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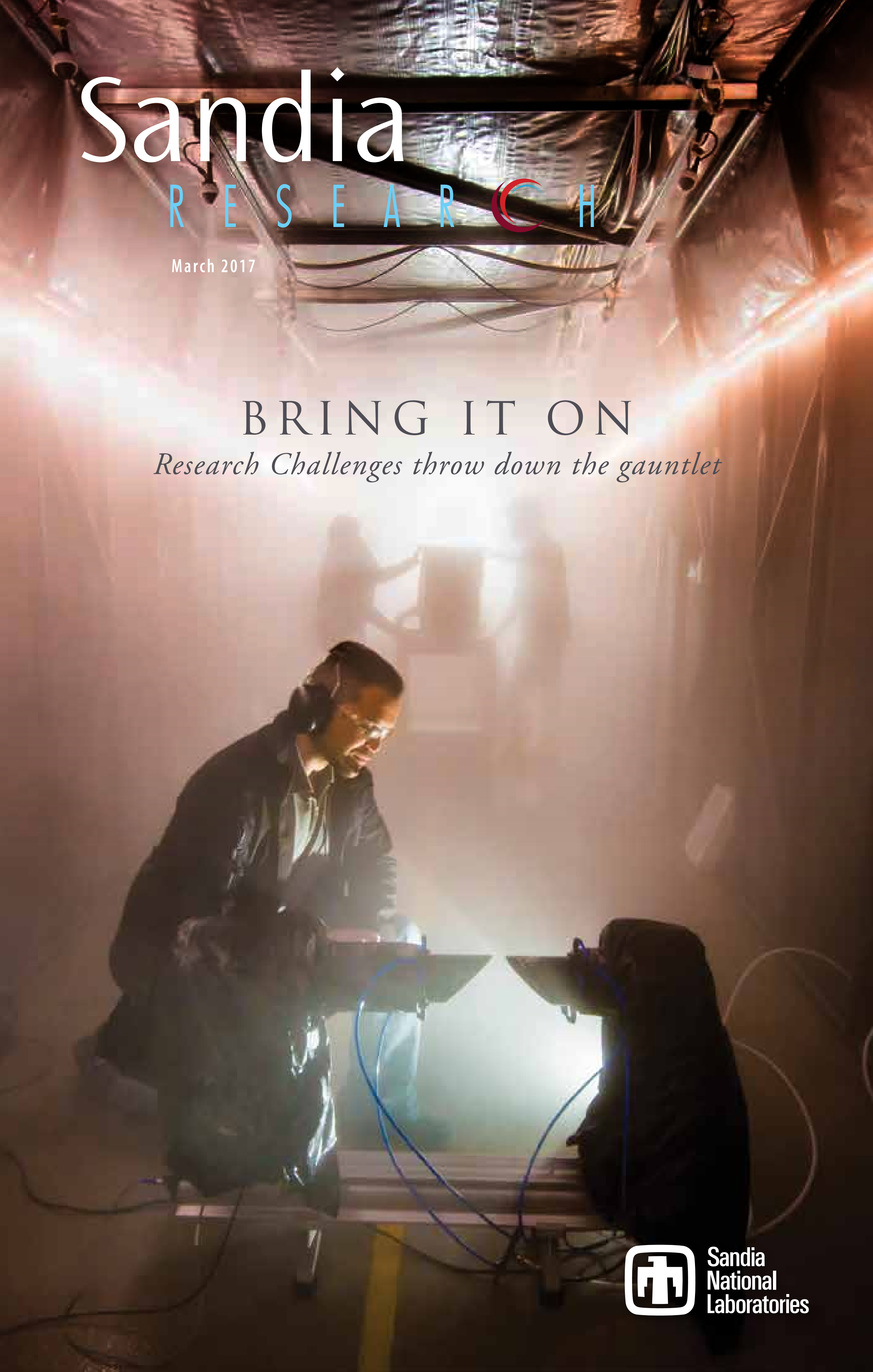

BRING IT ON

Research Challenges throw down the gauntlet

Sandia National Laboratories

Exceptional service in the national interest

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ON THE COVER

Research at Sandia Labs happens in dozens of cutting-edge facilities across campuses in Albuquerque, New Mexico, and Livermore, California. Here a fog chamber at Sandia/New Mexico is used to test optics in a controlled environment. Chemical engineer Andres Sanchez measures the particle size and concentration of fog in the chamber atmosphere.

(Photo by Randy Montoya)

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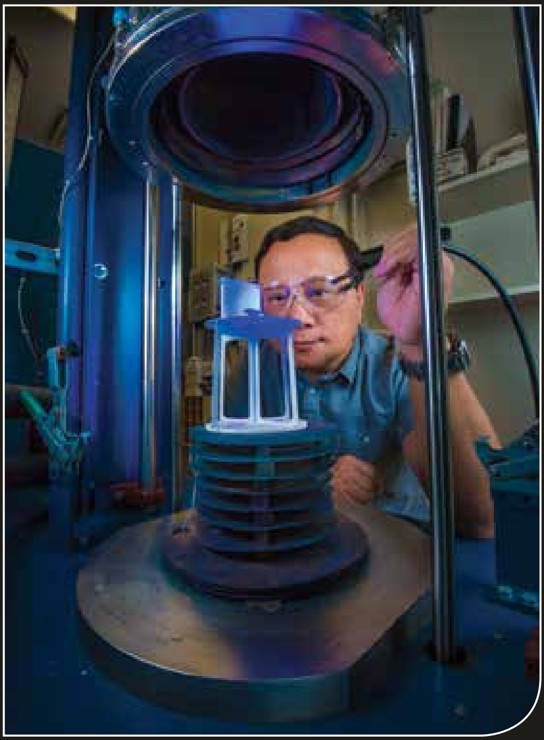
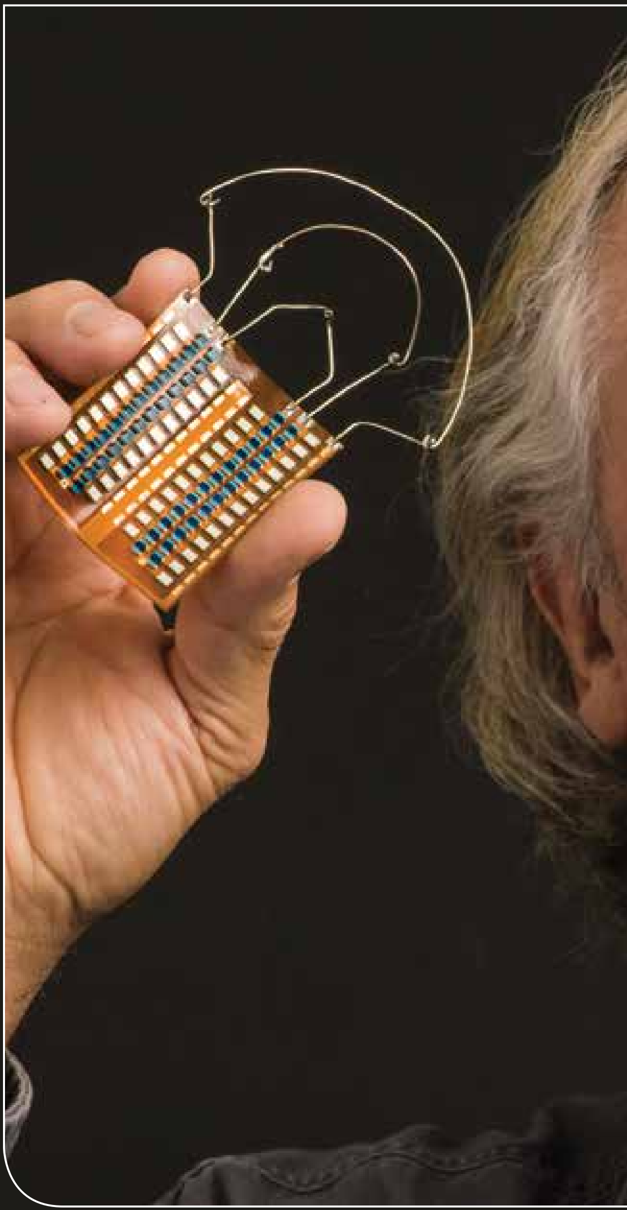
T H E

LONG GAME

Research at a national laboratory is often driven by tight deadlines. But what if a big idea needs more time to go from impossible to possible? A Research Challenge lets it play out and make a difference.

By Nancy Salem

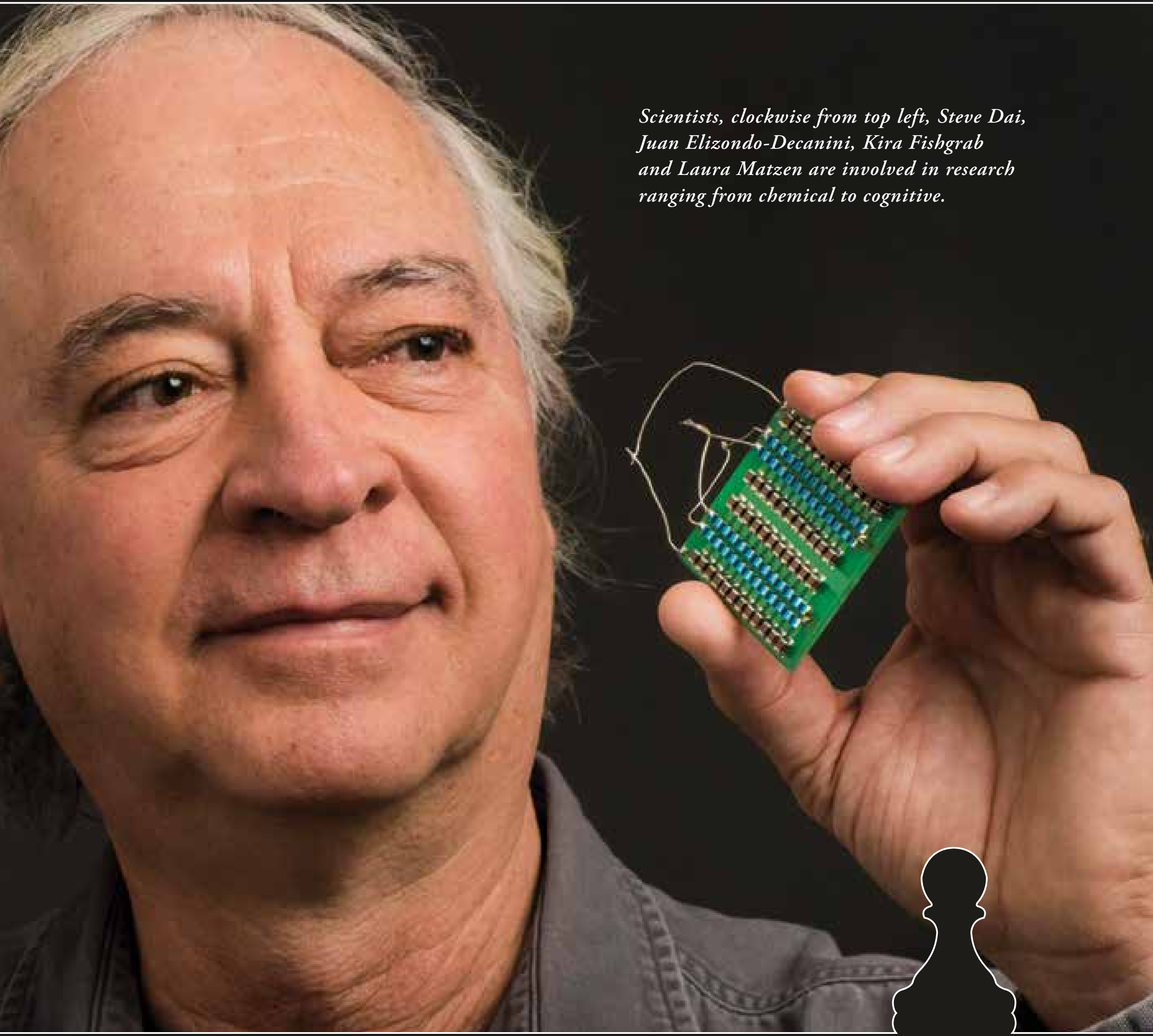




Sandia Labs is a famously mission-driven place. Thousands of scientists and engineers work every day to help the U.S. identify and defeat threats to national security, some nuclear, some chemical and biological, and some just plain terrorism.

Steve Rottler knew it when he took over as chief technology officer and vice president of research in 2009. He also knew that research is vital to carrying out the national security mission. “It was going to be very important for Sandia’s research community to have a sense of strategy that could be married with the mission,” he says. “Research should drive the mission, even as research is being responsive to the mission.”

And an idea was born.



Scientists, clockwise from top left, Steve Dai, Juan Elizondo-Decanini, Kira Fishgrab and Laura Matzen are involved in research ranging from chemical to cognitive.

As Rottler and his team developed a technical strategy for the future of research at the labs, the concept of Research Challenges emerged. “They were intended to be bold ideas that would excite and inspire the research community,” he says. “We wanted to better integrate mission with research and vice versa, and do it in a way that would lead to Sandia being recognized not only as mission oriented, but as a research powerhouse.”

Today Sandia has 11 active Research Challenges, organized and put into action largely by Julia Phillips, Rottler's successor as chief technology officer. They are designed to produce breakthroughs that impact the mission and contribute in their own right to advancing the frontiers of science and engineering. They are:

- Beyond Moore Computing
- Data Science
- Detection at the Limit
- Engineering Abiotic-Biotic Living Systems
- Engineering of Materials Reliability
- Power on Demand
- Pulsed Power Opportunities for Weapons & Effects Research
- Resiliency in Complex Systems
- Revolutionary Approaches to the Stockpile
- Science and Engineering of Quantum Information Systems (SEQIS)
- Trusted Systems and Communications

The hallmark of a Research Challenge is work that spans a decade or more and cuts across many disciplines, says Rob Leland, who succeeded Rottler as chief technology officer and VP of

Science and Technology after Rottler became vice president and head of Sandia's lab in Livermore, California, and later deputy laboratories director and executive vice president for National Security Programs. "What really sets them apart is the researchers are thinking strategically how to advance a technology across mission areas over a long scale," he says. "It's a compelling roadmap that envisions how we get from relatively basic early stage research to something that can have mission impact in a coordinated way using a combination of resources such as Laboratory Directed Research and Development [LDRD] and direct funding from multiple program areas."

Organize people on a larger scale

Research Challenges are part of a Sandia research strategy that includes the LDRD and Grand Challenge LDRD programs, which award funding through a competitive proposal process. LDRD projects run three years and have potential for strong mission impact. Grand Challenge LDRD projects, also three years, are larger and focus on bold, high-risk high-reward ideas.

The longer-term Research Challenges gain momentum when associated projects win Grand Challenge LDRD support. "We want to see the Research Challenges organize people on a larger scale, and Grand Challenges are one aspect of that," says Andy McIlroy, Sandia's deputy chief technology officer and director of Research Strategy and Partnerships. "Many of the successful Grand Challenge proposals are aligned with one or more of the Research Challenges. The proposals maturing out of Research Challenges tend to be particularly compelling and well thought out."

The LDRD program is funded as a percentage of all the programs that come into the labs, currently at about 6 percent or $155 million a year. About 20 percent of Sandia's LDRD portfolio is connected to Research Challenges.

Halfway into the 10-year vision, several Research Challenges are showing results and have won Grand Challenge LDRD funding, McIlroy says. The SEQIS challenge around quantum computing has made significant progress by coordinating efforts across a number of research fronts (see story on page 8).

"SEQIS is a model Research Challenge. They actually started behaving like a Research Challenge before the concept existed," McIlroy says. "The fact that we have qubits on a chip and a vision about how to connect those together and create what starts to look like a quantum computer on a chip would have been a big stretch five to 10 years ago. They have accelerated Sandia's position in that community to where we are viewed as being one of the leading research institutions in quantum computing."

And Power on Demand (see story on page 12) is moving strongly in multiple directions, propelled by several Grand Challenges, McIlroy says. One of them, on ultra wide bandgap, has published results showing it's possible to make transistors and diodes from advanced semiconductor materials that could perform much better than silicon, the workhorse of the modern electronics world. The breakthrough work takes a step toward more compact and efficient power electronics, which in turn could improve everything from consumer electronics to electrical grids.

"Their vision is getting out beyond Sandia and having impact," McIlroy says. "That's what we want with Research Challenges, something that will make a difference in the world."

Technical passion and skilled management

Research Challenges organize around technical staff and senior management who have a strong interest in the area. "They bring together the technical passion and some ability and expertise around marshaling and leading a larger effort. The most successful challenges have both those components," McIlroy says. "What matters most is passion and excitement around the Research Challenge, a vision to drive it forward."

The teams build organically around the technical and executive leaders. "The strength is the community that comes together," McIlroy says.

Sandia computer scientist Rick Muller, who works on the SEQIS quantum computing challenge, says it has been a high point of his technical career. It was eye-opening to collaborate with people from different disciplines, he says. "These are the best people I've ever worked with," he says. "The research plan we put together explores new applications of quantum technologies that will be important to Sandia and the nation over the next 10 years, something that was particularly exciting given the team's diverse strengths."

A panel of laboratory fellows and senior scientists reviews the Research Challenges each year to see if they are headed in the right direction. "We're coming to believe there should be an end point to a Research Challenge, maybe 15 years out," McIlroy says. "If constructed in the purest form, they are trying to address a challenge and at some point we will have gotten there. We're still trying to tease out what the graduation requirements are. We're pushing them to have a concrete thing they reach for, a game-changing concept. At some point the work is no longer a challenge but a fundamental part of the capabilities that drive the lab forward."

Mathematician and computer scientist Tim Trucano, who chairs the review panel, says the value of a Research Challenge is in its power to integrate the lab and provide the time and space to move down a complex path with a goal in mind, at the end delivering compelling, mature and usable research results. "They are essential because of what they're trying to do," he says. "This work is critical to the lab and to the nation."

Rachel Trojahn sets up a test of Sandia's Global Burst Detector in the labs' Flight Test Chamber.

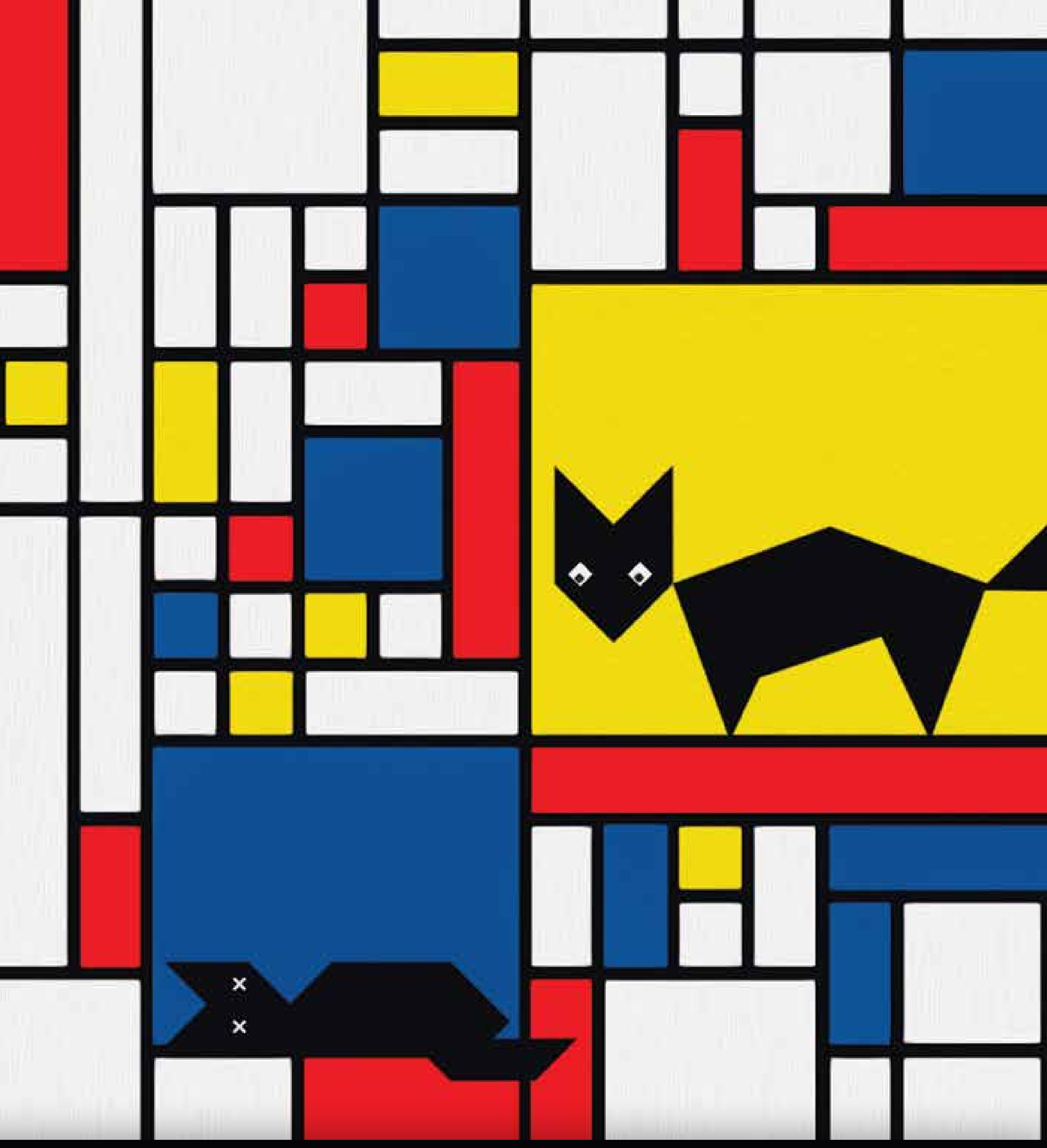
David J. Martinez checks a cooling system at Sandia's supercomputing center that works like a refrigerator without the expense and energy of a compressor. It's called the Thermosyphon Cooler Hybrid System.

A pure vision

Leland says the Research Challenges fulfill Sandia's mission as a Federally Funded Research and Development Center, or FFRDC, by advancing the state of the art in science and technology. "The challenges are a pure expression of that," he says. "We're creating a vision to solve a problem that we think has national importance. We figure out how to connect the dots to make that happen and get where we want to go. FFRDCs should be taking a leadership role in pushing the state of the art."

Rottler says the challenges have helped integrate research at the labs and produced world-class, world-recognized science. "I'm pleased with the trajectory," he says. "We should continue trying to get better and better. For me there was never a destination. It was and is a journey."

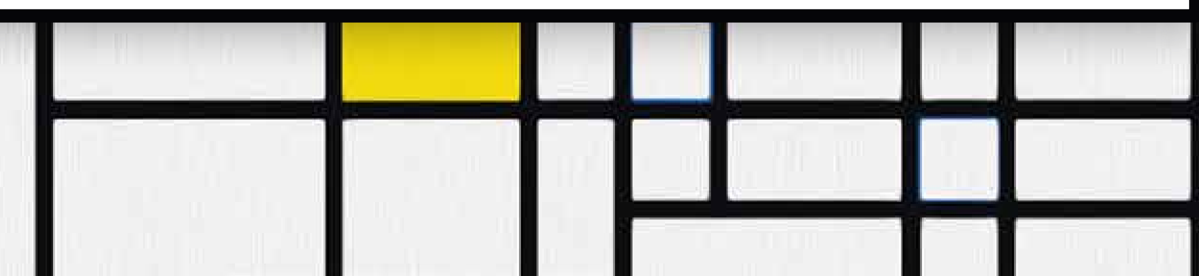
Leland says the challenges show the value of a national laboratory. "We can address an issue that's important that might be outside the scope of what people are even thinking is possible today, and pursue it so that in 10 years we've got something ready to go," he says. "People might think, 'Maybe that's possible.' We can say, 'It's not only possible, here it is.' That's what a national lab can do." ■



MIND BOGGLER

By Neal Singer

With its qubits, entanglements and curious rules, quantum information can seem incomprehensible. But scientists are making sense of the riddles and shaping a remarkable quantum future.



A favorite story for those introducing the strange concepts of quantum science has to do with a cat postulated by a famous physicist, Erwin Schrödinger, to be neither alive nor dead, but maybe both, as it lay in a closed box. Only when the box was opened did the cat become either alive or dead. This paradox is so famous, though its meaning obscure, that even the non-technical *New Yorker* literary magazine ran a cartoon in 2015 of a man in a veterinarian clinic being told by a sympathetic nurse, "About your cat, Dr. Schrödinger — I have good news and bad news."

Schrödinger's fabled cat metaphor was his way of criticizing the prevailing school of thought in quantum mechanics and has both fascinated and befuddled people to this day.

Quantum physics — the fundamental theory of nature at small scales and low energies of atoms and subatomic particles — is difficult to understand because the behavior of particles at a subatomic scale contradicts everyday logic. That difficulty is partly why Sandia physicist Andrew Landahl became a quantum information scientist rather than a theoretical physicist: He says it's easier to deal with what you can *do* with the rules of quantum mechanics than understanding how the rules *work*.

"Like a chess player," he says, "I'm happy to accept the strange rules at face value and instead spend my time working out how to use the rules to play a great game."

Quantum applied to national security

The application-focused "do" approach has produced impressive results.

"The SEQIS (Science and Engineering of Quantum Information Systems) Research Challenge at Sandia is now pushing unique capabilities out to all of our mission areas," says Landahl. "We are now a go-to place across the entire federal government for quantum information science solutions to national security problems, cutting across stovepipes and impacting the whole laboratory."

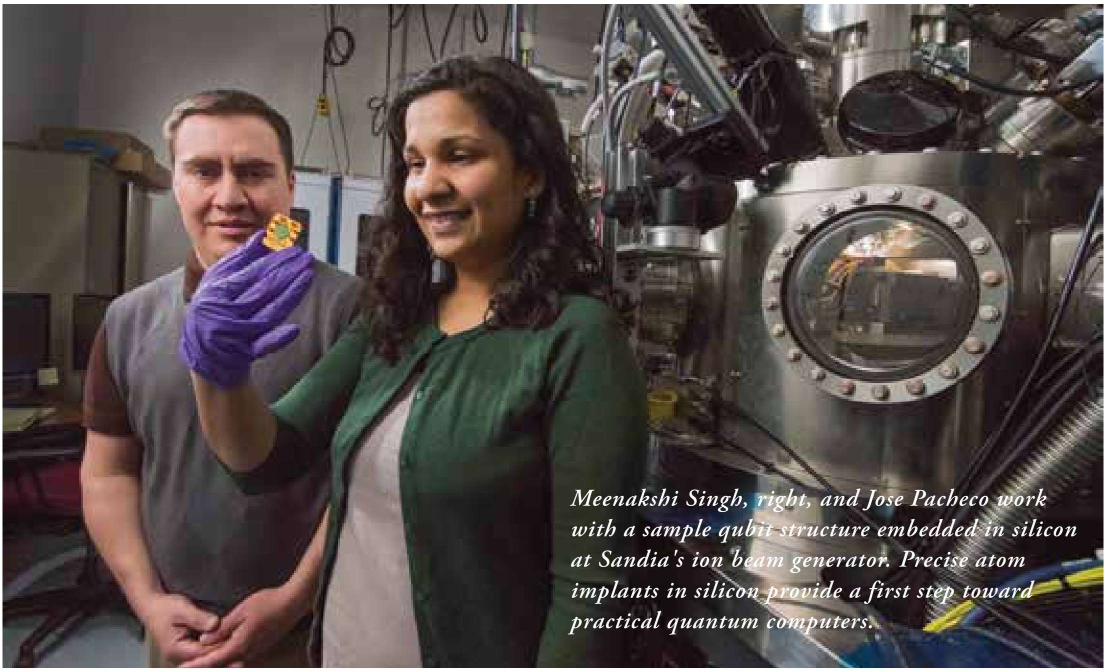
While some claim that a functioning quantum computer could crack many cryptography systems on Earth, including ATM codes and conventionally classified emails, the technique has more positive aspects. "We can build quantum seals to certify bonded transport or secure nuclear materials: Quantum seals are not locks, just extremely sensitive devices that can detect if even a single photon has been tampered with. And we can remotely monitor it; we don't have to physically enter a radioactive area to read the sign," says Landahl.

Quantum methods may eventually supersede the militarily vulnerable GPS satellite system that tells us where we are.

"Quantum information science is extremely practical," amplifies Landahl. "At Sandia, we've used it to build an atom interferometer that traps atoms with laser beams so that the atoms act like a combination of an ultra-precise gyroscope, an accelerometer and a magnetometer all in one. This could outperform the GPS system by more than a factor of 1,000 and also work underground and underwater where satellite signals can't reach."

That is, GPS can't help users when its signal is blocked by significant earth or water, but the atomic interferometer knows where it is and what time it is, in a basement or while scuba diving, just fine.

"The business end of our device currently fits in a shoebox, but the surrounding laser system still fills an entire optical table," says Landahl. "Still, we have ideas for how to miniaturize that. GPS *could* be obsolete in 10 years because of quantum information science. "



Meenakshi Singh, right, and Jose Pacheco work with a sample qubit structure embedded in silicon at Sandia's ion beam generator. Precise atom implants in silicon provide a first step toward practical quantum computers.

A race to dominance

The U.S. currently enjoys a dominant position in information technology, he says, but that place is being challenged. "While our nation's IT dominance is the envy of the world – we created the Internet, Google, Facebook – we could easily lose it. It may surprise you that the United States is not dominant in quantum information science. For example, China and Europe are each investing more than us, to the tune of billions of dollars.

Quantum information technology researchers produce more than 30,000 technical papers a year worldwide. This has stimulated investment from Sandia's Laboratory Directed Research and Development (LDRD) program of $75 million since 2003. Sandia now can fabricate chips an atom at a time — one of two places on Earth able to do that — a helpful capability in building a quantum computer.

Maintaining the U.S. position in the 21st century will require advances in quantum information science: the intersection of quantum mechanics and information theory.

"Industry is now coming to Sandia for quantum information technology transfer," Landahl has said in public talks. "They see a big future market in all of this. Market intelligence estimates peg the market at $5 billion by 2020. Both major companies and focused startups are getting on board. IBM alone announced in 2014 that it's investing $3 billion over five years into the field. Quantum information science is going to be the business of the world, and it's already becoming the business of our laboratory."

On and off at the same time

The necessary ingredient throughout this work is the quantum bit — a qubit, which, like Schrödinger's cat, is a switch that can be both on and off at the same time until it is measured. To form the switch, nature provides a wide variety of components: electrons judging which ions to infuse, atomic states, a particle of light or even the circulating current in a superconductor.

What makes qubits different from ordinary bits is the idea of quantum entanglement, a phenomenon in which the quantum aspects of several particles can't be described separately from each other. This quality let Sandia researchers in a Grand Challenge LDRD project called SECANT link weak quantum processors together, offering the possibility of new computer architectures rather than attempt the formidable task of building a single large quantum computer. It may also enable distributed quantum sensing using correlations from multiple sensors.

"Entanglement is like the gasoline of quantum information science," says Landahl. "It's the source of all of the power."

To which may be concluded: May the entangled quantum force be with us. ■

MEET

Ryan Camacho

Ryan Camacho is a family man who spends a lot of time thinking about kids, his and others', and where they are in life. He thinks back to the people who influenced him and how it guided his course.

Growing up in San Jose, California, Camacho's path wasn't clear. His father is an accountant and his siblings gravitated to business and the arts. But he enjoyed problem-solving. "I was the kid in class who liked math. I don't know where it came from but going into science seemed like a good idea," he says.

Camacho started college as a triple major — physics, electrical engineering and chemistry — and dropped two within a year. Physics was left standing. "It took me a while to know what direction I wanted to go, but then I knew," he says.

His first lab partner in grad school had worked for Sandia and talked to Camacho about Albuquerque and the labs. Others talked about teaching, and after doing a postdoc at Caltech, Camacho considered taking a faculty job. Around the time he was applying, a Sandia recruiter came by and, reminded of his lab partner, Camacho signed on in 2010.

He works in quantum information science. "The flavor of my research has been doing quantum communications on a chip," he says. "We are showing that you can do a lot of spooky quantum physics and put it on a useful, working microchip." He works on Sandia's Science and Engineering of Quantum Information Systems, or SEQIS, Research Challenge.

"It's been amazing," Camacho says. "Having a community at Sandia that's interested in all aspects of quantum is terrific."

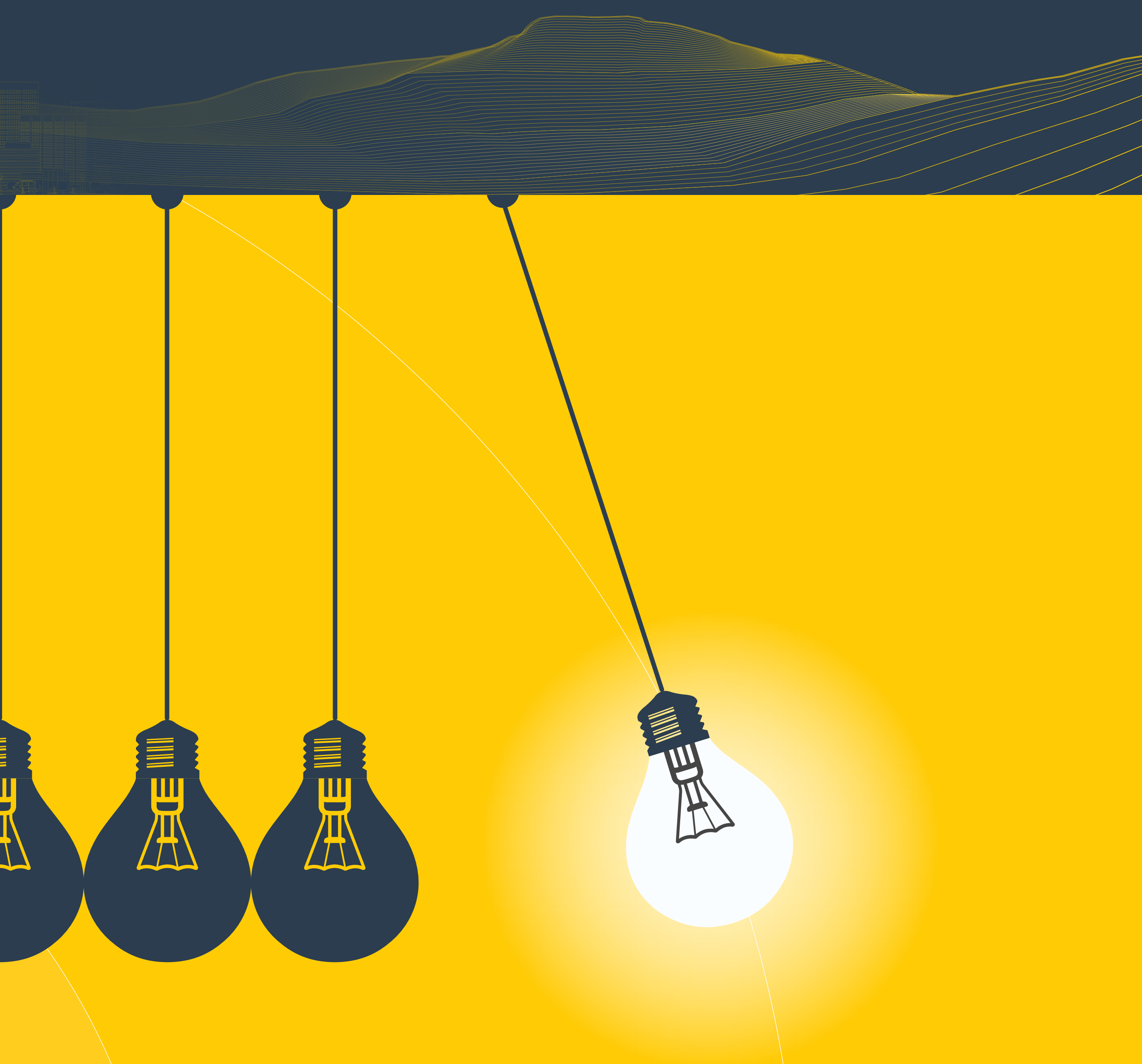
Camacho shares what he has learned in life with youth in Albuquerque. He coaches math and chess and does science bowl programs in middle schools. "STEM [science, technology, engineering, and math] outreach is important to me," he says. "I remember how it helped me as a kid. I want to be a part of other peoples' lives."

— Nancy Salem

The world wants smaller, lighter, more efficient power systems — electricity where it's needed, when it's needed. A tall order, but the payoff would be huge.

SUPER POWER

By Sue Major Holmes



Sandia National Laboratories wants to invent the electrical future.

The modern world runs on electricity. But the power needs of an electrical grid to serve a large city are not the same as those of a sensor placed in the middle of nowhere to detect intruders.

Sandia formed its Power on Demand Research Challenge about three years ago, building on work the labs had done for decades in everything from semiconductors to materials science. Olga Spahn, Semiconductor Material and Device Sciences manager, calls the Research Challenge a coalition of the willing that also acts as a matchmaker between technologies and users.

The idea is to accelerate revolutionary technologies that will form the backbone of the electrical power systems of the future: exponentially increasing the speed, efficiency and performance of electrical power systems while decreasing their size and weight and therefore cost.

“The key to Power on Demand is to say: ‘Science could have an impact; let’s work on this,’” says Radiation and Electrical Sciences Director Charles Barbour. Goals include developing advanced semiconductor materials and devices, and improving batteries while helping solve research questions for Sandia’s critical national security work.

Research Challenges are long-range projects — in this case, 10 to 15 years — that draw from multiple fields to respond to wide-ranging, important questions.

The civilian world wants secure and sustainable electrical sources for everything from transportation to large-scale power generation, while the defense realm has power needs ranging from electric ships to satellites. Both want smaller, lighter and more efficient electrical power systems providing electricity when they want it and in the form they need.

Smaller, more powerful electrical systems

Power on Demand aims to develop electrical power systems with the smallest size and weight for the largest possible amount of energy, what's known known as SWaP, for size, weight and power. That requires tackling underlying fundamental science questions and complicated technical demands to make better devices, materials and power systems.

The payoff could be huge — an efficient and smart next-generation power grid, better electrical motors for industry, energy storage and conversion for renewable power, better battery technologies for electric and hybrid vehicles, autonomous sensors in remote locations, electricity for forward-operating military bases, extended robotics lifespans, more efficient nuclear weapons subsystems hardened against damage from radiation, and compact, reliable and radiation-hardened power conversion systems for satellites.

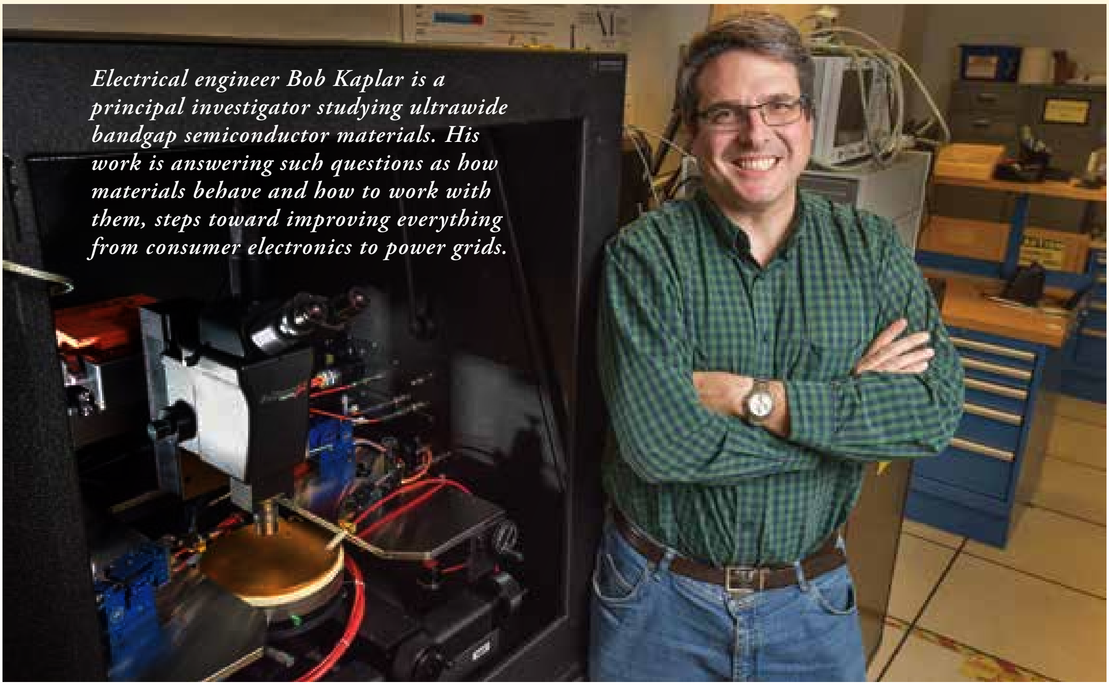
Sandia's Power on Demand Research Challenge is divided into three technology focus areas: high-density storage of electrical energy in extreme environments (special batteries); ultracompact power electronics (wide and ultrawide bandgap semiconductors); and high-efficiency, low-weight harvesting of spectral energy (microsystems-enabled photovoltaics). Another area cross-cuts these three to address how to integrate storage, switching and distribution into different types of systems. It includes issues such as balancing power across asynchronous systems that require both steady power and pulsed power in a single system.

How everything fits together

"The three technology focus areas highlight different aspects," Spahn says. "We think about a system's pieces, how they all go together."

The first focus area, battery-based energy storage, explores battery-powered, high-performance electrical energy storage for mobile power and pulsed power applications.

Researchers in the second focus area are looking both at wide bandgap and ultrawide bandgap ad-



Electrical engineer Bob Kaplar is a principal investigator studying ultrawide bandgap semiconductor materials. His work is answering such questions as how materials behave and how to work with them, steps toward improving everything from consumer electronics to power grids.

MEET

Olga Spahn

When Olga Spahn isn't working on optical and microelectronics research at Sandia, she can be found hanging out with her family and with other scientists. She rides with the Penultimates, a bike team with a membership that's 98 percent Sandians, and trains for triathlons, road bike races and the MS150 held at summer's end. She describes the MS150 as a two-day, 150-mile trek that benefits muscular dystrophy and allows her to "enjoy the beautiful scenery of New Mexico, food, camaraderie, mutual suffering and the workout."

Spahn manages Sandia's Semiconductor Material and Device Sciences department, and has done research in optical and microelectronics at the labs for 23 years. She's a program manager for the Ultrawide Bandgap Power Electronics Grand Challenge Laboratory Directed Research and Development project and a deputy for Sandia's Power on Demand Research Challenge.

She sees compound semiconductors as an exciting area of research.

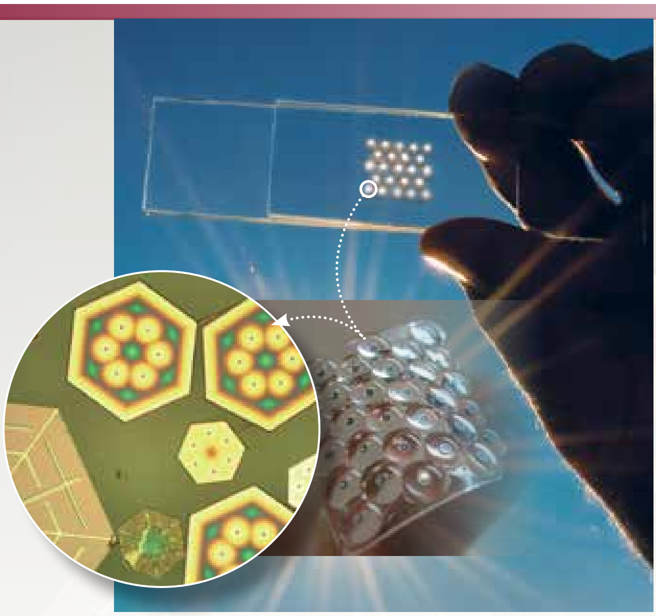
"My passion is connecting this unique, differentiating technology with program needs and executing both the science and the application to profoundly impact our national security missions," she says.

Her research has spanned a large variety of topics, including development of optical trapping, laser cutting and automation for particle forensic applications, laser-induced plasmas as analogues of macroscale explosive phenomena, characterization of laser welding and additive manufacturing processes. She also has worked on microelectromechanical systems (MEMS)/photonics integration and optical effects in MEMS, microfabrication of compound semiconductor optoelectronic devices such as lasers, modulators and detectors, and integrating them into microsystems.

— Sue Major Holmes

vanced semiconductor materials for power electronics that will allow electricity to be distributed where it's needed with smaller, lighter and more efficient power converters. Power electronics are vital for electrical systems because they transfer power from a source to the load, the user, by converting voltages, currents and frequencies.

Sandia in the past year sponsored two ultrawide bandgap material and device workshops, one in Albuquerque and one near Washington, D.C. A roadmap that outlines research needs was developed as a result of these meetings, says Sandia Fellow Jerry Simmons, a long-time researcher in semiconductor materials.



Sandia's microsystems-enabled photovoltaics, known as solar glitter, use microdesign and microfabrication to produce flexible miniature solar cells that could be used in buildings, clothing, portable electronics, vehicles and other contoured structures.

The challenge's third technology focus, microscale photovoltaics, is studying wireless power transfer by what's known as microsystems-enabled photovoltaics, with the goal of transmitting electricity across free space more efficiently.

The work got a head start through a microsystems-enabled photovoltaics (MEPV) Laboratory Directed Research and Development (LDRD) Grand Challenge that wrapped up in 2014. MEPV uses microdesign and fabrication techniques to make tiny solar cells that are released into a solution similar to ink, which is "printed" onto a substrate with embedded contacts and mini-lenses to focus sunlight onto the cells. The tiny, thin cells reduce the cost of materials while improving generation. They have potential uses in buildings, vehicles and portable electronics. An especially compelling use is in satellite applications, which need to harvest photovoltaic energy at the lowest possible weight.

Projects link technologies

Power on Demand also has three different central, major demonstration projects, each of which ties the three focus area technologies together and encompasses related research and development projects, some of which are funded by Sandia's LDRD program. The demonstration projects pull researchers from diverse fields all over Sandia to work together.

The first demonstration project, mobile pulsed power, will develop portable power systems that can store, switch and distribute baseline power loads but also can handle short, high-power pulses without damaging or disrupting other loads in the system. "We have to think about how to do combined [types of power] which we can't do now," Barbour says.

Success will require improving and integrating technologies in energy storage and power electronics; developing new materials; shrinking all parts of a circuit, including capacitors and inductors; and improving overall delivery systems and controls, Spahn and Simmons say.

The second demonstration project centers on an alternative bus-based power distribution for nuclear weapons to reduce costs and increase radiation resistance and reliability in harsh environments. Power buses manage electrical power distribution that allows modularity in the weapon. The demonstration project is being undertaken in a new Grand Challenge LDRD project, "Enabling Modular Architectures with Radiation-Hard Bus-Based Power Delivery," under principal investigator Jason Neely in Sandia's Radiation and Electrical Sciences Center.

The third demonstration project involves remote sensing for site security. Researchers want to develop a power system that would enable remote power delivery to a network of sensors, requiring a targeted design of an energy source and storage, power conversion and distribution. It would use microsystems-enabled photovoltaics to provide power in far-flung locations, with the photovoltaics contoured to fit their environment. In addition, the sensor's batteries potentially could be recharged by beaming power from another location.

"They could reconfigure themselves, communicate with each other and call home when they sense something," Simmons says. Similar capabilities also would be useful for satellites.

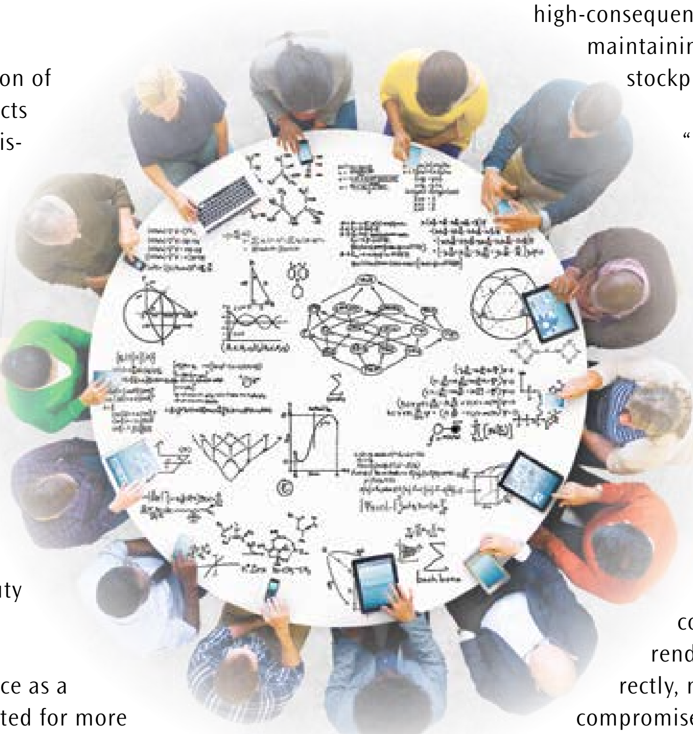
Sandia's long-term goal for the Power on Demand Research Challenge is nothing less than enabling a revolution in electrical power technology. While the existing demonstration projects all encompass national security needs, future demonstrations could involve civilian energy. "The nation's electrical grid, and its resilience against weather events and solar electrical storms, is getting increased attention by Congress," says Barbour. "We think the technologies we're developing in Power on Demand can help with that problem, too. It may be our next demonstration project." ■

Data science digs through an avalanche of information

START MAKING SENSE

By Stephanie Holinka

Sandia's Data Science Research Challenge doesn't look like a typical research challenge. Rather than a single challenge that all participating groups are working on, it includes a large collection of different projects, divided into seven areas, whose work covers a wide range of mission areas.



"The large collection of data science projects spans all of the missions of Sandia, including nuclear weapons, but also cyber, remote sensing, critical U.S. infrastructure and others," says Enhanced Decision Making senior manager and Data Science Research Challenge co-deputy John Feddema.

He says data science as a discipline has existed for more than 30 years; however, it recently became a fast-growing field of study because of the explosion of big data analysis on cloud computing platforms.

Data science research areas Sandia is concentrating on include:

- Feature extraction, including tensor analysis
- Graph and clustering analysis
- Event correlation and classification
- Uncertainty quantification
- Advanced analytic environments
- Multi-INT (multiple intelligence) data and model fusion
- Visualization and human cognition
- Sensor tasking and planning

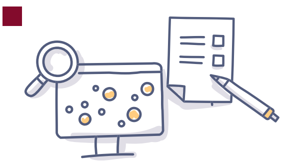
At its core, data science involves making sense of data for many different reasons. Expertise in data science requires skills and perspectives from mathematics, statistics, computer science, and also detailed subject-matter expertise. "For nuclear nonproliferation, we want to know where other countries are in their nuclear ambitions. For cybersecurity and critical infrastructures in the United States such as power grids, we want to know that our assets are secure," Feddema says.

He says Sandia is developing algorithms and software tools to deeply analyze data and come up with results detailed and robust enough to support high-consequence missions such as maintaining the nation's nuclear stockpile.

"Many companies are using machine learning and neural networks for classification, and these commercial applications are very good. But you have to bring it a notch beyond the current commercial techniques for national security applications. If a commercial application renders a street incorrectly, national security isn't compromised. Sandia is developing new machine learning algorithms to assist in high-consequence systems, when you have to be right every time," Feddema says.

The Research Challenge, which is two years into its 10-year roadmap, focuses on geospatial problems. "If you're looking for 'patterns of life' activities in remote sensing data and you want to pick out off-normal events, then you want to look at the statistics of those normal trends," Feddema says.

He says that pulling data off the web, or generating data via remote sensing systems like synthetic aperture radar (SAR), can result in petabytes of data, but ultimately sense needs to be made of the data. "When we have a large amount of data and we have to boil it down, we try to reduce things down to a set of features," Feddema says. "Sparse information is represented in graphs very well. At the end of the processing chain is visualization and human cognition, to give people the right information they can be confident in to make decisions. And next is sensory planning — if you have these expensive assets you need to put sensors in the right place to gather sensor information." ■



Pediatrics OR GERIATRICS

By Sue Major Holmes

A nuclear weapon has a life cycle just like a person. But the aging process is harder to weigh. When is old too old? Time will tell.

It's complicated, making sure a nuclear weapon will work as designed.

A 1992 moratorium that ended decades of large underground nuclear tests, an aging stockpile and the need to refurbish weapons have transformed what's known as stockpile evaluation or integrated surveillance.

Sandia National Laboratories, which is responsible for some 97 percent of the non-nuclear components of nuclear weapons, tested components in various ways even before the moratorium. Sandia's core mission is nuclear weapons, and over the years, it has developed ever-more sophisticated tests and increased computer modeling and simulations to qualify nuclear weapons — certify they will work as designed but won't work in an accident or when they're not authorized by the president, says Scott Holswade, Sandia's deputy chief weapons engineer.

Three years ago, Sandia formed a Research Challenge, Revolutionary Approaches to the Stockpile, to bring together a variety of experts to address, among other things, how to ensure a thorough understanding of how weapons age and what that means for a smaller, older stockpile. Research Challenges are longer-range projects that address important national security questions.

The Department of Defense (DoD) and the Department of Energy (DOE) set requirements for weapons. Sandia must consider all the environments weapons could face, such as vibration or radiation, then come up with designs to handle those and tests to make sure designs meet requirements, says Toby Townsend, stockpile systems engineering senior manager. Once weapons enter the stockpile, Sandia must continue testing to assure they meet requirements as they age.

Typically, a weapon has a so-called protected period, the lifespan it's designed for — 20 years, for example. Engineers certify it through such processes as accelerated aging, using environmental test chambers to speed up conditions the weapon could face over time.

"We're often asked, 'How much longer could the weapon potentially be good for?' That's a major part of the stewardship mission," Townsend says.

Stages of the life cycle

At one time, most weapons were either newly in production or fairly early in their life cycle and were retired before they aged much more than about 10 years. Now, the stockpile includes systems that have been there for decades and newly refurbished weapons that reuse some older parts with some new ones.

"A pediatrician does not look at the same things that a geriatrics expert would. The things you're looking for in 'pediatrics,' the defects in design and production, are different than if you're looking for aging effects for something late in its life cycle," Holswade says. "I think that's been the big evolution of the program, to start implementing changes that recognize this and the need to change the program to optimize for each system, depending on where it is in the life cycle."

A weapon coming into the stockpile, such as the refurbished W76-1, is tested at very high rates to catch possible design or manufacturing defects. However,

the question is different for a weapon that's been in the stockpile a while: How does aging affect it?

Jay Vinson, senior manager for Integrated Stockpile Evaluation, says assessments of the non-nuclear systems include laboratory testing, largely at the Weapons Evaluation Test Laboratory (WETL) at the Pantex Plant near Amarillo, Texas. Assessments also include non-nuclear system-level flight testing of gravity bombs at Tonopah Test Range in Nevada, cruise missiles at the Utah Test and Training Range, Air Force ballistic missiles flown into the Pacific from Vandenberg Air Force Base in California and Navy submarine-launched missiles flown in the Atlantic and the Pacific, he says. Numerous places, including Sandia, the Kansas City National Security Campus and WETL, do component tests.

During development of modifications such as a life extension program or an alteration, tests qualify individual components up to whole systems. "There

The Validation and Qualification Sciences Experimental Complex is a unique group of test facilities, including this centrifuge, that create a broad range of engineering environments used in Sandia's national security mission work.

will be temperature cycling, there'll be vibration, there'll be shock, there will be radiation, there might be voltage changes, all kinds of things that the system is subjected to, done in accordance with a plan that combines testing with simulation to make sure we're working through in a systematic way what's required to qualify the weapon for operation," Holswade says. "The goal is absolute certainty that the design is good to perform."

Tests and more tests

Once production begins, the program must assure the as-built weapon conforms to the as-designed weapon. "You can have production errors, or you may have missed something in the design process that only reveals itself as you get to higher volumes," Holswade says.

Vinson says that as production ramps up, Sandia does more retrofit evaluation sample testing, pulling units before they go into the stockpile to catch possible production errors or early-onset failures.

Weapons also are pulled from the field to test later when they've been handled by military personnel and might have been on a submarine or missile. At that point, engineers want to study whether field conditions exposed a problem.

Some weapons from the field are built into joint test assemblies, mock weapons without nuclear materials but fitted with sensors and instrumentation to assess performance. Flight testing is part of the qualification process for refurbished weapons, and its main objective is to obtain reliability, accuracy and performance data under operational conditions. Scientists and engineers use the test data in computer simulations developed by Sandia to evaluate systems' reliability and to verify they functioned as designed.

The W80-1 Air Launched Cruise Missile Surveillance Flight Test Program fielded a joint test assembly in June, simulating a long flight to a target and performing arming maneuvers. "In this case, the nuclear explosive package is replaced by the testing assembly, so the system won't detonate, but it will function with all the Sandia componentry along that trajectory," Vinson says. "The various safety functions and other weapon functions will occur as if it were a wartime environment. We want that to all work properly because it indicates we have a safe and reliable weapon."

Weapons in some flight tests have high explosives that detonate, with instruments sending out data during flight. In other cases, instead of explosives, sensors in the system check that the detonation chain would function. Instruments send out the data during flight but engineers recover that system afterward for further diagnostics. For B61-12 flight tests at Tonopah, real-time telemetry data gathered during flight tests are monitored and verified at the range's Test Operations Center and main telemetry ground station and sent to Sandia in Albuquerque.

Top photo, left to right, Juan Elizondo-Decanini, Kevin Youngman and Matt Senkow discuss neutron generators.

Left, in the ongoing effort to refurbish the aging B61 nuclear bomb without underground testing, Sandia engineers completed two successful B61-12 radar drop tests at the Tonopah Test Range in Nevada.

MEET

Kina Winoto

In high school, Kina Winoto wanted to be an FBI agent or join the military. She thought about the Naval Academy for college. “Weirdly enough, I always wanted to work for the government,” she says. Her parents urged her to wait to enlist, so she enrolled at the University of California, Los Angeles.

She was drawn back to government after graduation and did an internship at the Department of Defense, where she heard about Sandia Labs and its national security mission. “That really resonated with me,” she says. “I homed in on that type of work.”

Winoto’s role model was her dad, a molecular cell biology professor at the University of California, Berkeley. “He tried really, really hard to get me into science, and it was fun,” she says. “I have great memories of experiments and Lawrence Hall of Science camps and science fairs. He pushed me to ask questions.”

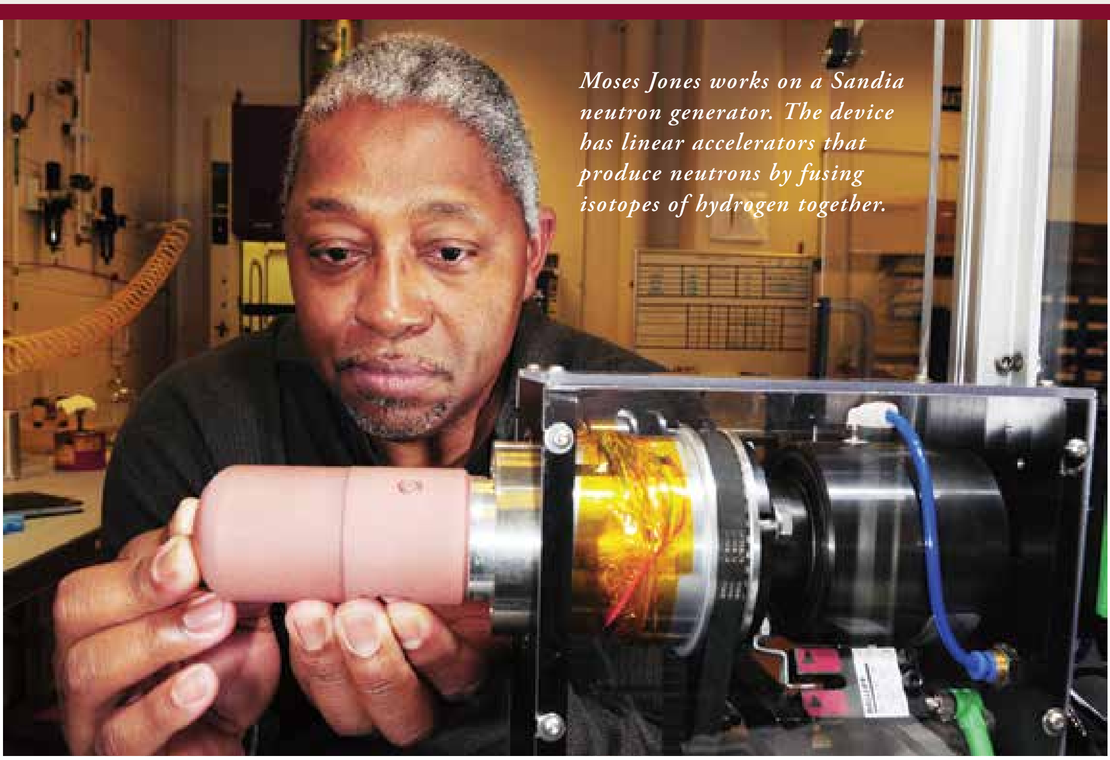
Winoto took her first computer science class as a high school freshman. Another was offered her sophomore year, but that was it. She wanted to know more and enrolled in computer science in college. “I didn’t get enough in high school,” she says. “I remember a moment in my third year of college when I thought, ‘Wait, am I majoring in computer science?’ I hadn’t really thought about it. I just kept wanting to learn more.”

Winoto joined Sandia in 2012 and earned her master’s degree through the labs’ Critical Skills Master’s Program. She works in cybersecurity where her focus has been on integrating state-of-the-art techniques with mission-critical data. A lot of her work has been in data analytics in the cyber application space. But Winoto is a jack of all trades, having worked in everything from software development of big data processing tools to applied statistics. She’s working now on bringing numerical linear algebra techniques to mixed-type datasets to let analysts more efficiently identify anomalies.

In her spare time Winoto raises and helps train guide dogs for the blind. She builds furniture with her fiancé and does acroyoga, which combines yoga and acrobatics.

“Sandia has really shaped my career as a data scientist and inspired me to work on mission-critical problems.” she says. “On the path I’ve taken, every day brings new and exciting discoveries.”

— Nancy Salem



Moses Jones works on a Sandia neutron generator. The device has linear accelerators that produce neutrons by fusing isotopes of hydrogen together.

"We can't fly every potential trajectory because you're limited by where you can launch from and where you can land. We can't fly every weather condition because you're stuck with the weather you have when the flight's scheduled," Holswade says. So engineers do additional tests on components and subsystems for those "corner cases" — like the hottest day with the biggest shock condition or the coldest day with more vibration.

Simulation anchored by experimental data

Sandia's large environmental test facilities can evaluate components under a wide range of conditions. That doesn't mean testing is easy — combining environments is especially challenging. Engineers might test how well a component works in a radiation environment, but it's difficult to combine radiation and shock testing, for example. So researchers use simulation anchored by experimental data. That lets researchers assess components when it's not realistic to test every possible scenario, Townsend says.

"It gives us a lot more confidence across the spectrum of environments," he says.

Because Sandia is responsible for nuclear weapons parts that must have a high degree of reliability, materials scientists, engineers, computer scientists, modelers and others also are working on projects under a separate Research Challenge, Engineering of Materials Reliability. That program is focusing efforts on understanding how the variability of materials can affect stockpile performance, with the goal of building a foundation to understand and predict the limits of a material's performance and its contribution to reliability of engineered structures.

"Sandia has to guarantee the part works for decades," says Amy Sun, a member of the leadership team for the research. "It's an inherent challenge to understand how materials perform, under what conditions a material changes its property and whether a part we want to design can tolerate those changes that come naturally with aging or an external influence like the weather. It's important we invest early to anticipate what problems there may be in the future."

The Research Challenge incorporates and broadens many materials and engineering efforts, including Sandia's Predicting Performance Margins project and other Laboratory Directed Research and Development and Advanced Simulation and Computing activities that study how variability in materials' atomic configurations and microstructures could affect how actual parts perform. It includes several demonstration projects, including the Brittle Materials Assurance Prediction initiative, which is studying the properties of materials such as glass that can fail catastrophically, and "Born Qualified," which is looking at new materials challenges and opportunities posed by additive manufacturing.

"We consider stockpile stewardship as our most important mission for engineering materials reliability, but we know that it's relevant to all mission areas at Sandia where materials reliability is one of the requirements," Sun says. ■

BEYOND MOORE

By Stephanie Holinka

AS THE GOLDEN AGE OF ELECTRONICS WANES, SCIENTISTS LOOK FOR A NEW INFORMATION HIGHWAY

The Beyond Moore Computing Research Challenge looks at when the techno-economic theory that has proven true and driven the electronics revolution could come to an end.

Moore's Law is named after Intel co-founder Gordon Moore's prediction in a 1965 paper that the number of transistors per square inch of integrated circuit would double every year. He said at the time that the growth rate would continue for the foreseeable future.

For decades, Moore's Law steadily increased microelectronic chip performance and gave people the integration of video recording, personal digital assistants, computers, radios, clocks, GPS and more into smaller and smaller devices at relatively low consumer cost and without an increased need for power in the devices. But it enabled far more than that; it produced an electronics golden age. Moore's Law is more an economic theory than a technological one since it relates to the innovation cycle that brings increasing computing power to the world. "Right now, companies fund increasingly large investments in R&D, leading to a technical leap in chip performance, which can then sell for a lot of money, which funds the next investment and the next technical leap," says Research Challenge senior manager Rick McCormick. "After dozens of these cycles over the last five decades, the leaps are getting much harder and orders of magnitude more expensive, so it's increasingly difficult."

A growing information economy

Consumers tend to view the technology progression a "law" and want more and more. Computing is woven into almost all aspects of business and personal lives and the growth in consumption is exponential. "Throughout the first couple dozen innovation cycles, we got the performance increase using the same power, and at little increase in cost to the

Sandia researchers are studying the brain, including these green fluorescent protein-labeled neurons in a mouse neocortex, with the aim of developing neuro-inspired computing systems.

consumer. Who could resist that? It has enabled an information age and our growing information economy," McCormick says.

But over the past decade, the $300 billion semiconductor industry started bumping up against both economic and technical speed bumps on the information highway. Dennard scaling, which kept the power density on a chip constant while the number of transistors and performance increased, began failing in the 2006 timeframe. This stopped the increases in clock speeds that marked the prior cycles. Chip performance improvements have continued but are now due mainly to just having more transistors and clever chip architectures (more processing "cores"). Transistor scaling and novel micro-architectures could continue current performance improvement trends for another six to10 years, though fabrication costs may slow the cycles. But projected trends of "computing consumption" may outstrip this progress.

"Without something new, in about 15 years, information and communications technology could go from using 3.5 percent of the world's electricity to nearly 30 percent," McCormick says.

"We need a new path to scaling, to find a new way to support steady performance and energy improvements, as we've grown accustomed to. That's a lofty goal," McCormick says. "It took us about 60 years to get here. We can't afford another 60 years to find the new approach, or suffer the economic and national security risks associated with getting left behind."

Computing beyond Moore's Law in the 2030s will take revolutionary new devices, manufacturing processes, architectures and algorithms in addition to the projected progress of current approaches. There is a lot of research going on worldwide around the problem, including at Sandia.

Tough, revolutionary innovations

"It'll take a lot of research — deep material science, device physics, circuits, chips, packaging, component qualification, architectures, and Sandia does all of that at a fairly impressive level," McCormick says. "But Sandia really excels at taking tough, revolutionary innovations and making them practical. At our heart, we're an engineering lab. We do a lot of science, but where we excel is at transitioning fundamental science into applications, things like figuring out how to manufacture, even at low volume, and figuring out how to make things reliable and resilient. We do a better job at coupling together the pieces, and that's unique."

The Research Challenge has held two town hall meetings, and a team of several dozen Sandia scientists is looking to develop a method to unify a number of the disparate research efforts. The aim is to make the research more efficient by systematically validating early stage work prior to the projects undergoing years of research. This would allow researchers to know early in the process if a new device proposal would have a large energy impact on a particular architecture running a particular application. Sandia has broad and deep expertise at all levels of this framework and a proven ability to merge modeling and experiment to deliver the sort of multi-scale design codes that could accelerate research in the area.

Kathye Chavez works on Sandia's Red Sky supercomputer, one of the fastest computers in the world.

The Research Challenge has rapidly expanded, including opportunities to help lead a national lab team that presented the energy challenge at the Energy Department's Big Idea Summit last spring. It was well received and continued collaborations between the labs have led to discussions with industry, academia and other government agencies about potential initiatives to address this critical issue. ■

THE BIONIC PLAN

By Mollie Rappe

Living and non-living materials don't have to keep their distance. Bringing them together can create hybrid systems for a bold new world.

Augmented super-soldiers, self-healing materials used in cars and airplanes and using genetic engineering to fight off infections sound like things straight out of science fiction. And they are, for now.

Sandia's ENgineering Abiotic-Biotic Living Systems (ENABLS) Research Challenge aims to turn science fiction into science fact. More specifically, ENABLS is tackling the molecular-level interface between biology and non-living materials to engineer hybrid systems that combine the strengths of both.

"ENABLS will take what we know about materials, what we know about biology and how biological systems interact with their environments, and build a more capable way of interfacing the two," says Steve Casalnuovo, deputy for the Research Challenge.

Even the humblest bacterium is an expert at sensing, responding to and manipulating its environment, says Casalnuovo. But, living things are quite fragile and can be killed by changes in the environment, including temperature, pressure, radiation and chemicals. Man-made materials are generally robust over a broader range of conditions but lack biology's exquisite ability to sense and respond, he adds.

By bringing together biologists, chemists, physicists and materials scientists, ENABLS seeks to take the strengths of both biology and non-living materials to make something even better: a hybrid system that can be tailored and optimized according to different needs, says Casalnuovo.

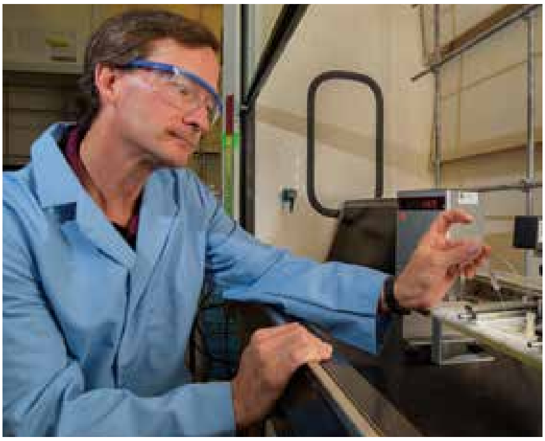
Oscar Negrete leads a Sandia project that is creating screening libraries based on CRISPR genome-editing technology. The libraries will help researchers rapidly understand how removing specific genes from a host cell affects virus infection.

Slice and dice pathogenic invaders

ENABLS' first effort is the NanoCRISPR Grand Challenge. This bold, three-year project combines recent advances in biology and nanomaterials to develop adaptable, safe and effective responses to biological threats and new pathogens, says Darryl Sasaki, principal investigator for the challenge.

Using porous silica nanoparticles to deliver a powerful new genetic engineering tool, CRISPR (clustered regularly interspaced short palindromic repeats), to where it needs to act, the NanoCRISPR team hopes to slice-and-dice the genome of invaders for public health and biodefense.

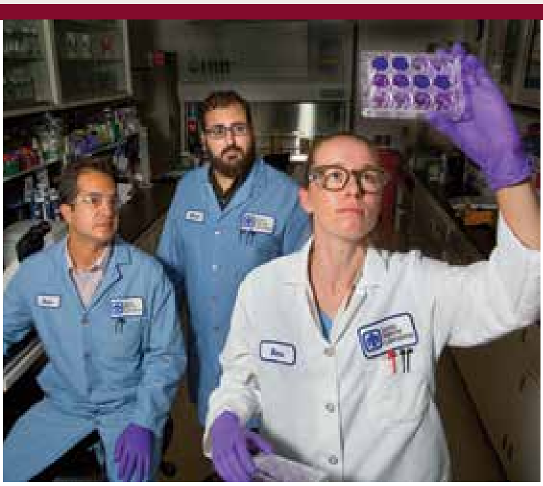
Unlike previous genetic engineering tools, such as zinc-finger nucleases or TALEN constructs, the CRISPR system is more adaptable, more precise and has transformed biology since major advances in 2012. Like previous genetic engineering tools, however, the CRISPR system by itself cannot target and enter cells and is thus ineffective without a delivery system.



Nanobiologist Mike Kent developed a hybrid technique to study how a critical HIV protein changes shape to let infected cells evade the immune system.

That's where the nanoparticles come in, says Casalnuovo. They can envelop and protect the delicate complex as it travels through the body. The outside of the nanoparticle can be coated with signaling molecules that camouflage the particle and direct it to the right place, such as the invading pathogen or specific organs and tissues targeted by the pathogen.

Sasaki says they have made great strides in encapsulating the biological cargo in the nanoparticles, delivering the cargo to model cells and triggering a genetic change. Through computer modeling, cellular assays and animal model studies, they hope to develop CRISPR-based countermeasures for the Zika virus and a drug-resistant bacterium.



Left to right, Sandia's Oscar Negrete, Edwin Saada and Sara Bird check out a CRISPR library preparation. Sandia is working on the project with UCLA through a Cooperative Research and Development Agreement.

Sandia's previous encapsulation work involved much smaller drug molecules such as antibiotics. Casalnuovo says CRISPR's protein-RNA complex is larger, more complex, more sensitive to the environment and needs to be delivered more precisely than the previous drug molecules.

Immune systems of the future

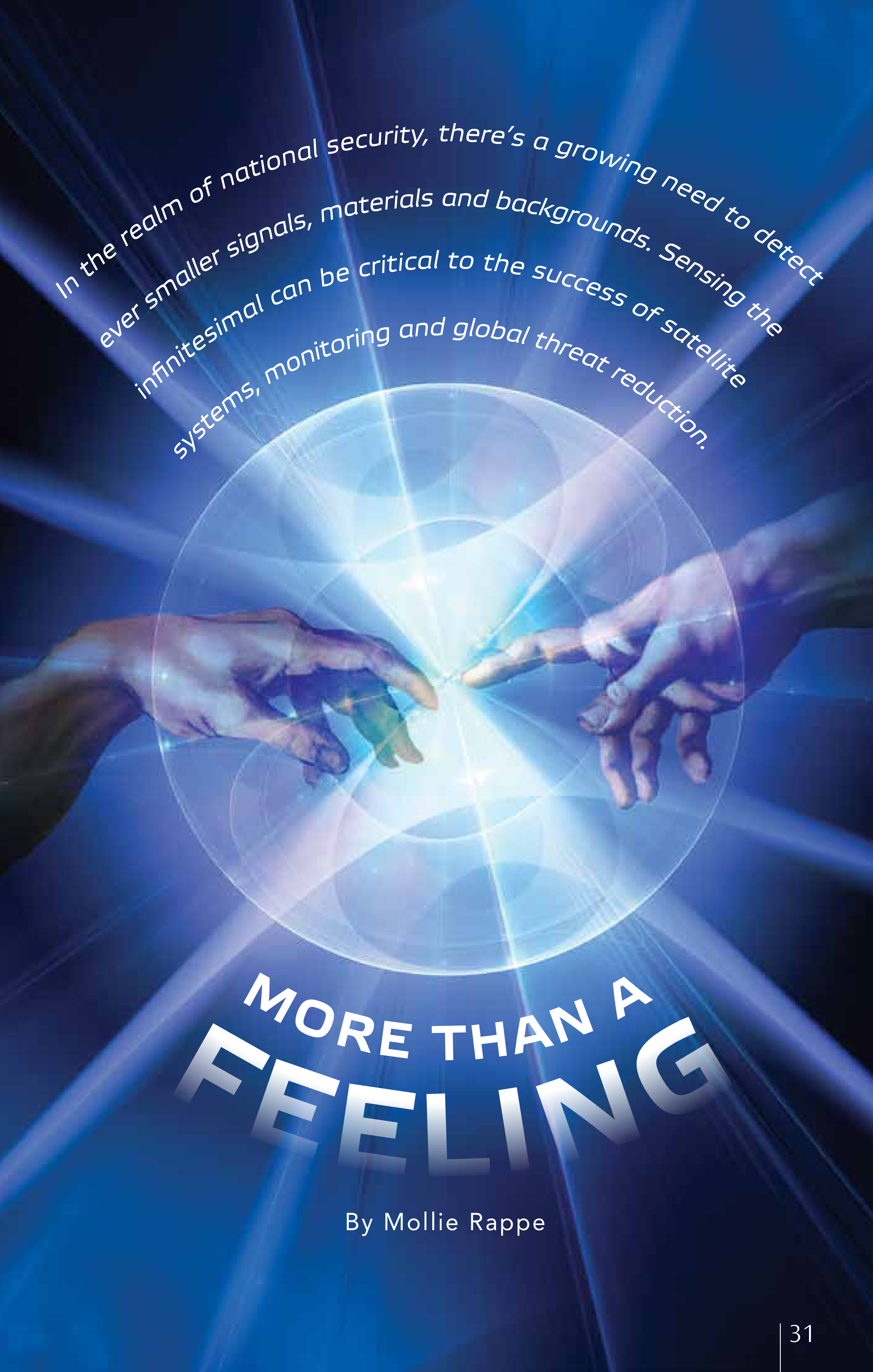
The next step for the ENABLS Research Challenge after the NanoCRISPR Grand Challenge is being evaluated. Possible paths forward include using biotic/abiotic nanoparticles to confer enhanced capabilities on the warfighter, developing a controlled microbial community in the human gut to serve as a first line of defense against infection or focusing on biotic/abiotic hybrids for energy-related applications or to make self-repairing materials.

Another possible path forward focuses on adapting the immune response in biological systems to make human-designed systems more robust. Many systems, from algae ponds grown for biofuels to mechanical structures, would benefit from the ability to recognize when things deviate from normal, learn from past experience, and initiate a repair, says Casalnuovo.

By fully understanding how nature employs biological design rules, researchers can improve non-biologic components, better interface the living and non-living systems and engineer the hybrid systems, Casalnuovo says.

"This is a hard problem from a lot of different perspectives. This Research Challenge is a 10- or 20-year effort, maybe even 50 years of work, with the potential for some really transformative things," says Casalnuovo. "This work has the potential to change the way we live." ■

In the realm of national security, there's a growing need to detect ever smaller signals, materials and backgrounds. Sensing the infinitesimal can be critical to the success of satellite systems, monitoring and global threat reduction.



MORE THAN A FEELING

By Mollie Rappe

Sandia's Detection at the Limit Research Challenge aims to push the limit of what can reliably be detected by sensors. It's a tall order. Detectable signals range from nuclear particles, to light — visible, ultraviolet and infrared — to radio waves, chemicals, pinpoint accurate location, and physical phenomena such as temperature and pressure. The various limits can stem from difficulties in sensitivity, selectivity, noise of different types, confidence of detection and even the robustness of the detectors in extreme environments.

What makes the vast challenge achievable is the team's concentration on Sandia's national security missions, ranging from satellite systems for defense and treaty monitoring to global threat reduction areas such as detecting chemical or biological agents and nuclear weapons.

"The Research Challenges are trying to bring together the science and technology community with the mission community and throughout almost every mission space we need to sense things. Even though the topic is extremely broad, by focusing on priority mission needs, it helps us to have a reasonable scope," says Mary Crawford, a senior scientist in the Research Challenge.

Researchers from Sandia's mission community are acutely aware of their sensing needs and limitations. For example, a sensor for a satellite system must be light and energy-efficient but able to detect an important color, or wavelength, of light. Researchers from the science community are experts in developing fields such as optoelectronics or phononics, says Wahid Hermina, a lead senior manager for the Research Challenge.

"The Detection at the Limit Research Challenge represents a seminal opportunity to Sandia as numerous government organizations strive to detect ever smaller signals, materials and backgrounds for various national security purposes," says Anthony Medina, director champion for the Research Challenge. "Ultimately, these government organizations want to know everything about the activities for which they are responsible."

Exquisite knowledge of what is seen

The first mission area the Detection at the Limit Research Challenge focused on was satellite sensors being developed through the Smart Sensors Technologies Grand Challenge Laboratory Directed Research and Development (LDRD) project. "Our first goal is to

Sensors are critical to national security.

MEET

Anna Tauke-Pedretti

Anna Tauke-Pedretti enjoys sewing one-of-a-kind outfits such as dresses with astronauts or elephants on them. "Sewing is a lot like engineering. It's figuring out how to put things together. There's a lot of math involved in figuring out how to modify a pattern, but it's a much quicker turnaround time," says Anna. "I can accomplish something in a weekend as opposed to a three-year program." And her daughters get something awesome to wear.

Tauke-Pedretti is an optoelectronic engineer, which means her day job is playing with light. She is a thrust lead for the Smart Sensor Technologies Grand Challenge, where she works on integrating unconventional ways to select a "color," or wavelength, of infrared light with conventional semiconductor detector systems. Sandia's nanoantennas can act like a filter and select one color from the rainbow of infrared light.

As part of the Microsystems-Enabled Photovoltaics Grand Challenge, she has worked on photovoltaic systems to make more efficient and smaller solar cells, also known as solar glitter, a spinoff from the Department of Energy's Advanced Research Projects Agency-Energy, or ARPA-E.

— Mollie Rappe

have exquisite knowledge of observables on the Earth as observed from space. By exquisite knowledge, I mean spatially, temporally and spectrally resolved information," says Hermina. In essence, the researchers aim to make sensors for satellites that know exactly what they saw — can tell the difference between a threat and smoke from a wildfire — where it was and when it appeared.

Sensors on satellites need to work in extreme environments, such as huge temperature swings and the high radiation in space. Often these conditions can make off-the-shelf detectors unusable, says Crawford. This is one reason why the researchers are interested in this challenge. Hermina adds that by "pushing the limits of the state-of-the-art in measurement" they can make sensors that can handle these environments while also being more sensitive.

Many innovations, for example, developing microscale sensors using nanoscale physics, have come from LDRD projects, including some projects conducted with partner universities. These basic research projects have contributed new ways of detecting infrared radiation, visible light and ultraviolet light — a wide region of the electromagnetic spectrum.

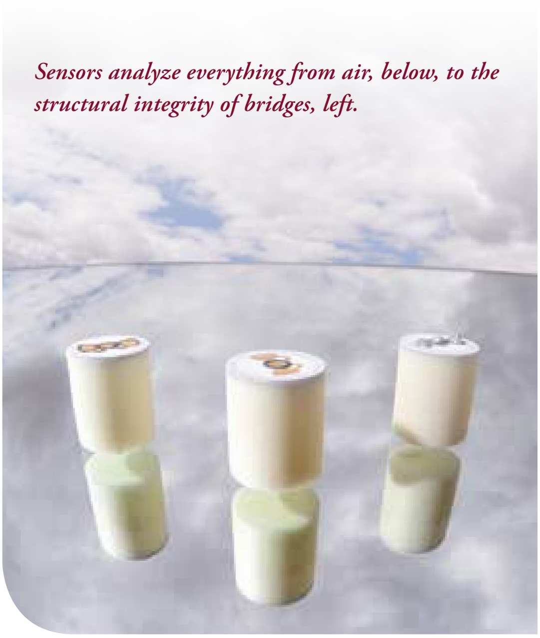
Researchers on the Smart Sensors Technologies Grand Challenge LDRD project also collaborate with the Power on Demand and Data Science Research Challenges, says Crawford. The Power on Demand researchers aid Smart Sensors Technologies in producing small and efficient power sources for the sensors. The Data Science researchers help Smart

Sensors Technologies determine how best to process and download all the detailed data generated by their new sensors.

The Grand Challenge aims to push the limits of detection, not replicate abilities already present in commercial sensors. However, if Sandia's new sensors have uses beyond the national security sphere, they will license the technology to others, as Sandia routinely does, says Hermina.

Next-generation sensors for nuclear weapons

The next national security need the Research Challenge will spotlight is nuclear weapons. Nuclear weapons need next-generation sensors that can evaluate the state of health of the weapon as indicated by measurements such as chemical composition. Also, next-generation nuclear weapons will need new sensors capable of measuring shock, acceleration and position.



Sensors analyze everything from air, below, to the structural integrity of bridges, left.

An important part of making progress in this area is getting the nuclear weapons experts and the science and technology experts together and speaking the same language. To this end, the Detection at the Limit Research Challenge has hosted three workshops that brought together about 100 researchers from across Sandia. A major goal was cross-education, says Crawford. Experts in scientific fields such as quantum sensing gave seminars on the current state of the art. Nuclear weapons engineers gave seminars on their future needs, and, in brainstorming sessions, researchers from both groups considered how to bridge the gap so that the emerging technologies could address anticipated needs, Crawford says.

"We're trying to nucleate a new Grand Challenge LDRD idea, which is at the crossroads of what the future mission needs are and what the cutting-edge science can accomplish," Crawford says, "I think it's really all about bringing those two communities together to address critical problems."

The Detection at the Limit Research Challenge is well situated to play a major role helping Sandia continue its legacy of national security work.

"Sandia's ability to serve future national security needs will hinge on our commitment to creating, developing and deploying technologies and systems that will enable us to help our customers know as much as possible about their targets of interest," says Medina. ■

When a complex system is damaged its recovery time holds clues to overall health

bouncing back

By Stephanie Holinka

Launched four years ago, the Resiliency in Complex Systems Research Challenge opened the door to a relatively new field of study with broad application across multiple areas of research.

The challenge defines a complex system as one with a large number of interacting parts, whose aggregate activity is nonlinear, that demonstrates emergent behaviors and is adaptive, meaning it changes over time.

“Most of the national security problems that Sandia is engaged in addressing are complex systems,” says Research Challenge co-deputy Marcey Hoover. “Researchers seek to analyze, classify and understand with certainty the resiliency of multiple interconnected systems in the face of multiple threats.”

The challenge looks at resiliency, or how successfully a complex system functions when damaged or disrupted, and how it recovers function over time. “Take a terrorist network, for example. Its success depends on many factors such as funding, key leaders and community support. If one or more of these factors could be influenced in certain ways, the system will operate very differently,” Hoover says. “Knowing which factors are most important and how much they need to be influenced is a goal of modeling complex systems. In this case, we would say we are making the system less resilient.”

The challenge is working now with Sandia’s Safe Secure Energy Future program, studying the electrical grid and infrastructure. “The idea is to understand infrastructure, such as the electrical grid, and find ways to quantitatively assess the health of the grid using resiliency as the metric. Right now we’re defining the hallmarks of resiliency. One measure that industry uses is ‘customer minutes interrupted,’ but there’s more than that. There’s security, reliability, cost and other metrics that would really feed into a resiliency metric,” Hoover says.

Another area of work on the grid project is creating a model of a constantly changing system, developing computer models that take into account grid operations, policy, regulations, things coming onto the grid like renewables and coming off the grid like the shutting down of coal plants. “If I can measure it, then I can find ways to change it either by how I design the system or how I operate it,” Hoover says.

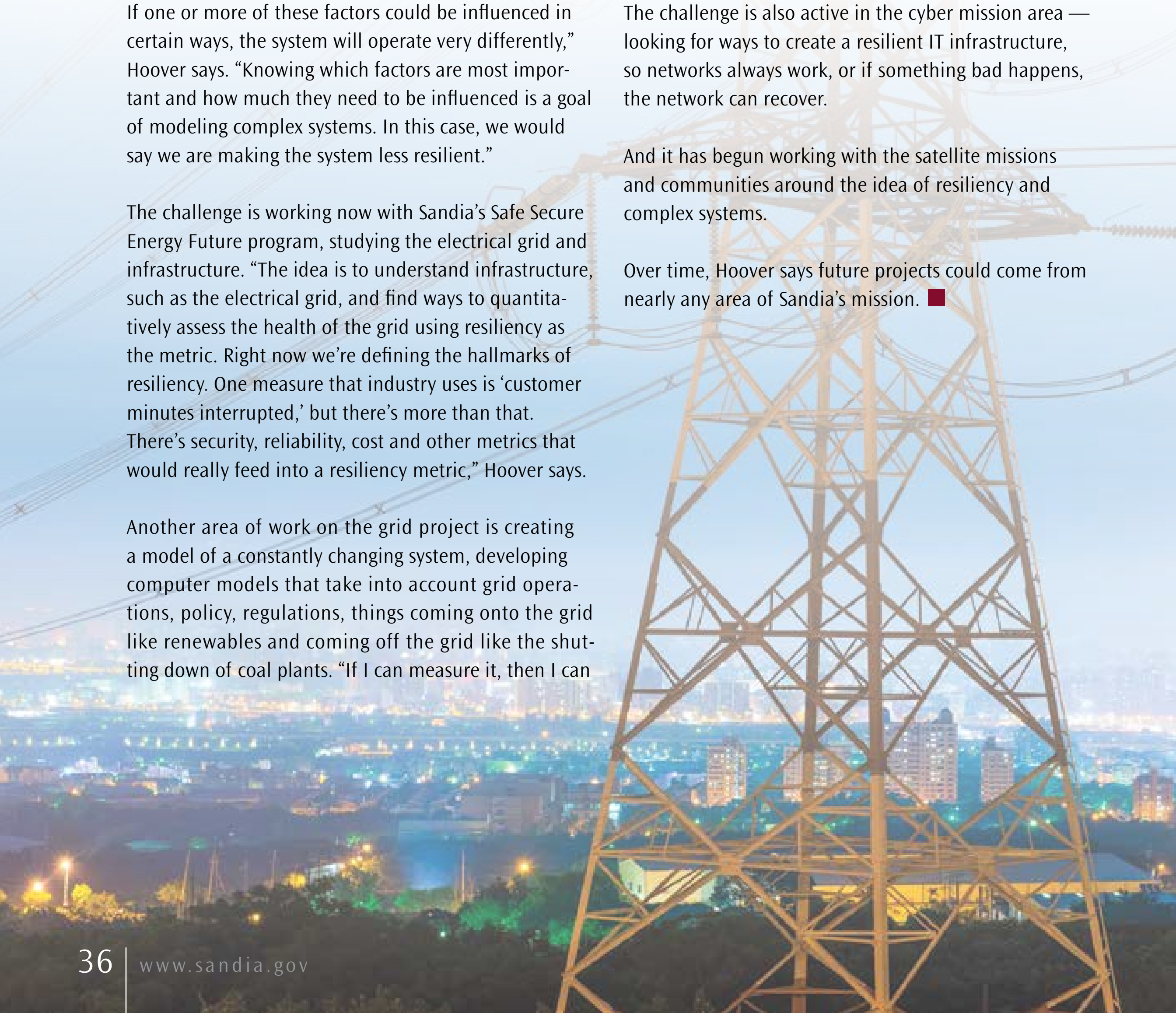
Researchers also are looking at whether there is a mathematical formula or theoretical underpinning of complex systems, trying to discover whether there are universal laws that govern complex systems and if there is something underlying all systems that is more universal.

Another project is trying to figure out how to validate a complex system model. “If you’re developing a physics-based model, then there is the opportunity to conduct experimental tests to validate the model. Often when modeling complex systems involving national security, it is difficult, if not impossible, to obtain data to validate the model. For example, we don’t have data for validating a complex system model of a terrorist event like a dirty bomb exploding in New York City. We are currently conducting research in how to validate complex systems models such as these,” Hoover says.

The challenge is also active in the cyber mission area — looking for ways to create a resilient IT infrastructure, so networks always work, or if something bad happens, the network can recover.

And it has begun working with the satellite missions and communities around the idea of resiliency and complex systems.

Over time, Hoover says future projects could come from nearly any area of Sandia’s mission. ■



MEET

Tim Trucano

Kids who flunk middle-school math don't generally go on to earn a Ph.D. in the subject and become a distinguished member of the scientific staff at a national laboratory. But that's exactly what happened to Tim Trucano. "I got a D in math in the 8th grade and an F in 9th," he says. "That was the path I was on. I was a relatively poor student who scored well in verbal on standardized tests and was told consistently that I wasn't any good at math."

Then Trucano changed high schools, found different teachers and friends, and picked up the autobiography of the famed mathematician Norbert Wiener. "I went from flunking to viewing math totally differently," he says. "The kids I hung out with did better in school and the story of Norbert Wiener's life was fascinating. Suddenly I got interested in math. It was something I wanted to do for a living."

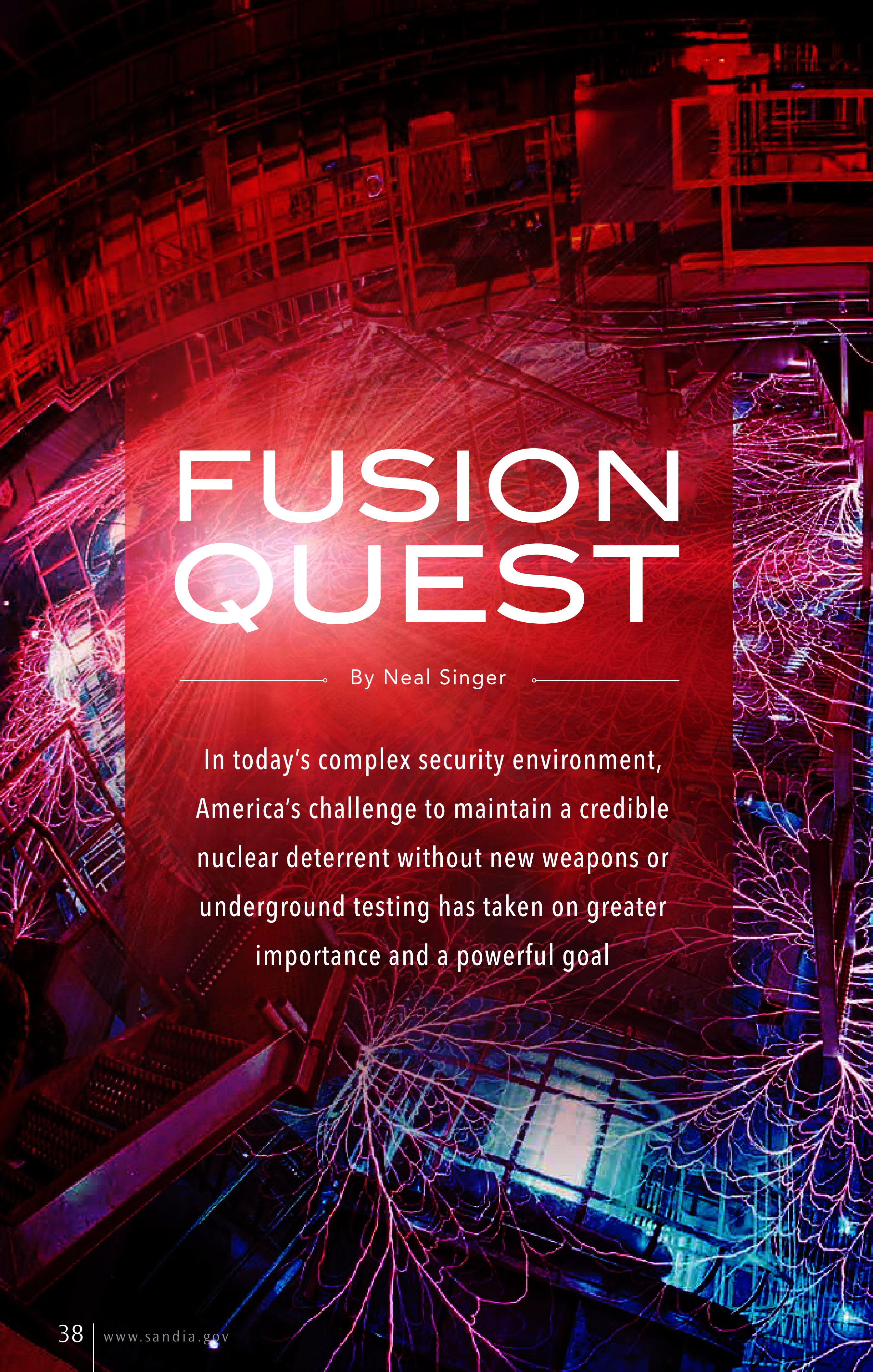
Trucano, whose family moved from Dayton, Ohio, to Albuquerque when he was a child, accelerated in math in high school, taking calculus as a senior. "I went from being told I couldn't do it to excelling," he says. "I knew I would major in math in college, I just didn't know what I would do with it."

He earned a bachelor's, master's and doctorate from the University of New Mexico. At the college placement office he noticed a job posting in Sandia's shock wave group, where he worked two summers as an undergrad. "They knew me," he says. "They got me in the door."

Trucano joined Sandia in 1980 and was named a distinguished member of the technical staff in 1995 and a senior scientist in 2005. His early career focused on research, development and applications of computational shock wave physics. In 1995 he shifted to verification and validation in computational science and applications of uncertainty quantification. He now works on technical and programmatic challenges for the National Nuclear Security Administration's Advanced Simulation and Computing (ASC) Verification and Validation program. As a technical leader for Sandia's work on the program since it started in 1999, Trucano has been a major force for the development and implementation of computational science verification and validation.

"The luckiest thing that ever happened to me was getting into Sandia," says Trucano, who reads and listens to music in his spare time. "I've been lucky in everything I've worked on and the people I've worked with. It's been the perfect career."

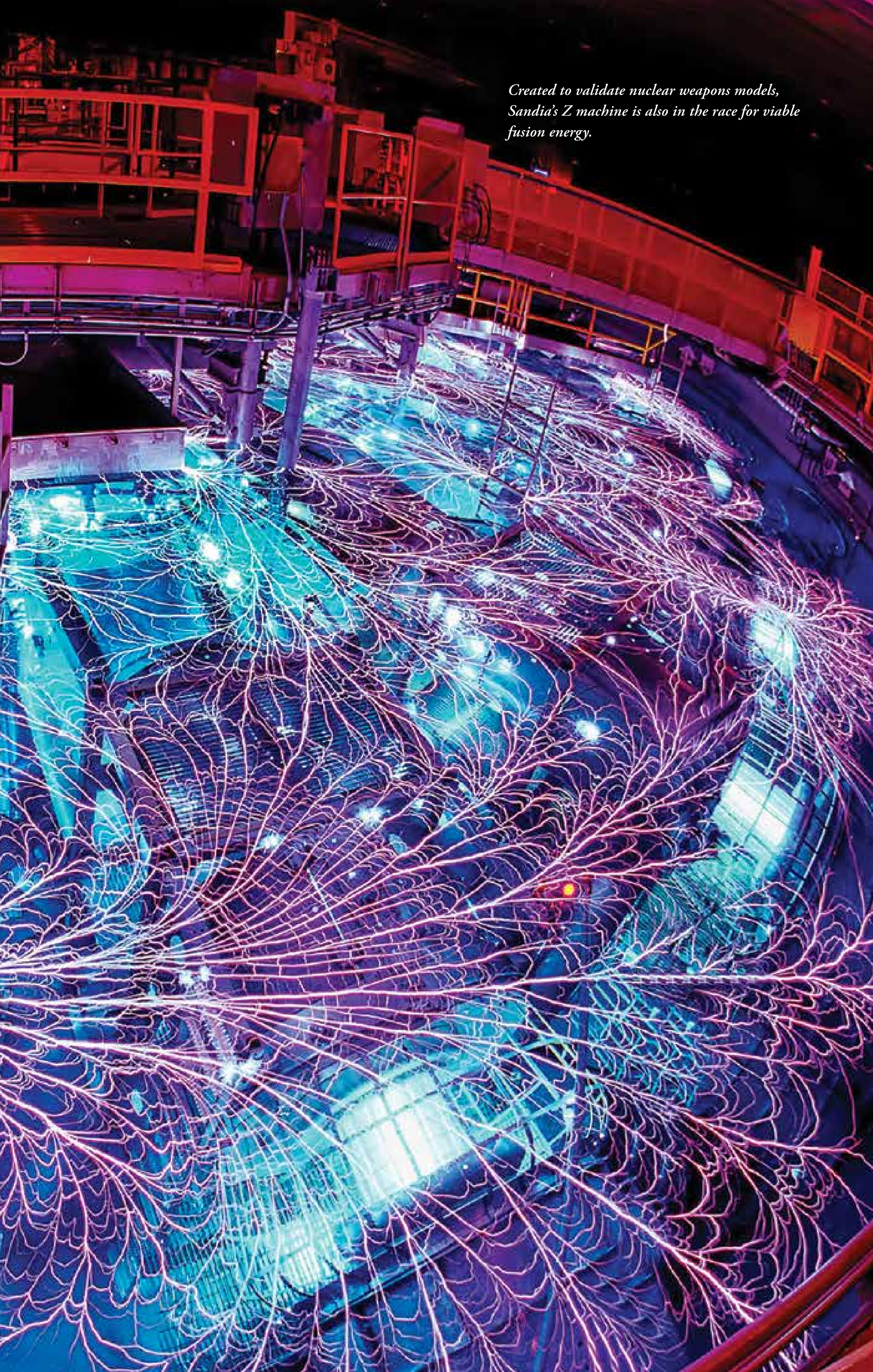
— *Nancy Salem*



FUSION QUEST

By Neal Singer

In today's complex security environment, America's challenge to maintain a credible nuclear deterrent without new weapons or underground testing has taken on greater importance and a powerful goal



Created to validate nuclear weapons models, Sandia's Z machine is also in the race for viable fusion energy.

The goal of a laboratory-based high-yield fusion capability within the nuclear weapons complex is to create an experimental platform to help assure that the U.S. nuclear weapons stockpile will perform as intended far into the future.

Since the beginning of the Cold War, deterrence has been a key element of the country's nuclear security policy. It requires that the United States maintain a credible nuclear stockpile capable of convincing any potential adversary that the adverse consequences of attacking the United States or its allies and partners far outweigh any potential benefit. The end of the Cold War drastically diminished the probability of a strategic nuclear war, which led to large reductions in the number of nuclear weapons.


Hostile shock testing of the W76-1 was done at Sandia's Light Initiated High Explosive facility.

However, the increasing interest from potential adversaries around the world in acquiring or developing nuclear weapons and delivery systems with expanding capabilities poses new security threats. In today's security environment, the challenge for the United States is to maintain a credible nuclear deterrent without increasing the number of weapons in the stockpile, or returning to full-scale underground nuclear testing (UGT).

A different kind of testing

The last U.S. underground nuclear test occurred in 1992. In 1995, the president established the science-based Stockpile Stewardship Program (SSP) to assess and maintain the U.S. nuclear stockpile without resorting to UGT. In the more than 20 years since, this program has achieved important advances in nuclear weapons science that have significantly enhanced U.S. capabilities to assess and maintain them without UGT. For example, these capabilities allow the United States to address questions such as the lifetime of stockpile systems due to aging materials and components and enable life-extension changes to nuclear weapons systems through selective replacements of materials or components.

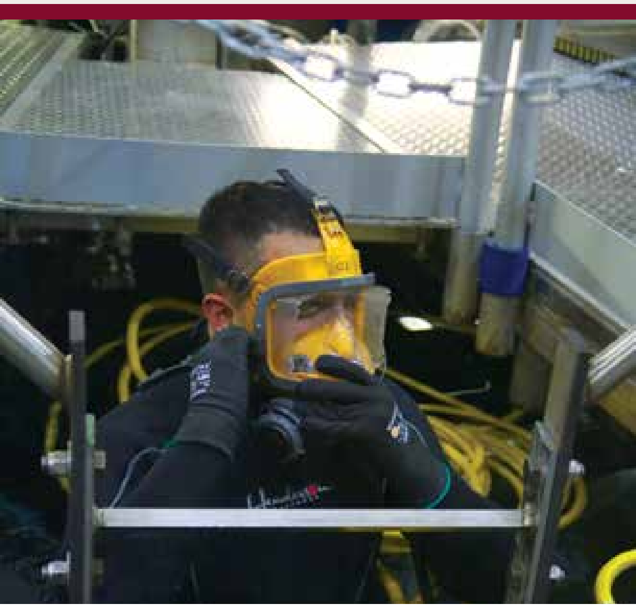
What current facilities cannot do is test the performance of nuclear components at actual threat levels or address many unanswered scientific questions about the performance of the nuclear explosive package. As UGT-trained designers continue to retire, increasingly complex stockpile questions will have to be answered by scientists without underground testing experience using legacy UGT data and experimental facilities that can reproduce the various physical phenomena intrinsic to a nuclear weapon.

In their January 2015 letter to the head of the National Nuclear Security Administration (NNSA), the three directors of nuclear weapons laboratories noted that the overwhelming majority of the yield of the nation's nuclear weapons is generated when the conditions within the nuclear explosive package are in the high energy density (HED) state. This requires that proficiency in HED science remains a core technical competency for the SSP for the foreseeable future. And the United States must continue to strive to be the first nation to demonstrate ignition and high yield in the laboratory. This goal is important not only because of its support for the SSP but also to send a strong signal to others regarding U.S. scientific and technical capabilities.

These are some of the goals of Sandia's Hostile Environments Laboratory Directed Research and Development

Work continues at an underground test complex at the Nevada Test Site 65 miles northwest of Las Vegas. It was the primary testing location for U.S. nuclear devices from 1951 to 1992, when the U.S. put a hold on full-scale nuclear weapons testing. While there are no longer explosive tests of nuclear weapons at the site, there is still subcritical testing to determine the viability of the U.S. arsenal.

A day in the life of Z: Each day, highly skilled technicians set up experiments that stretch the boundaries of pulsed-power science.



Grand Challenge project, which uses the unique laboratory conditions created by the labs' pulsed-power facilities for research on weapons and their effects. The Grand Challenge is an intermediate goal of Sandia's Pulsed Power Opportunities for Weapons & Effects Research Challenge.

The story of Z

Sandia's Z pulsed-power facility creates HED conditions or radiation/neutron outputs that are used to provide data and experience to the nuclear weapons modeling and design community in the areas of dynamic material properties, nuclear survivability and radiation effects, and inertial confinement fusion. "Sandia has the ability to meet many of the Department of Defense specified threat requirements by independently testing the response of components to neutrons, X-rays and gamma rays," says Sandia senior manager Dan Sinars. "But we presently do not have a source powerful enough to combine them all in a single shot for hostile environment effects testing. Studying them separately in different tests is important and is done today, but studying them and their result together in a single, combined test might produce a different result. This is one reason why high-yield fusion is the ultimate goal of the research that we're performing on Z."

Weapons effects and HED physics have been the motivation for congressional investments in Z, he says, rather than unlimited energy from seawater, a noble but still-distant fusion goal. "We provide data and experiences for nuclear weapons scientists. Our product is their better judgment," Sinars says. "We provide a larger view. Radiation transport, effects testing, plasma studies and a wide range of other physics feed into tools that scientists use to judge the efficacy of the stockpile.

"I believe a more powerful version of today's Z facility may be the most plausible technology path available to our country for achieving high yield."

This facility, temporarily nicknamed Z-Next, will be designed to meet the identified need for a 10-30 MJ (megajoule) yield capability within the next 20 years, on a path to eventually achieving high yield of more than 500 MJ. A facility capable of 10-30 MJ yields could address several key issues in weapon science, dynamic materials, effects modeling and fusion research that are not possible at existing NNSA facilities.

Sinars says that once researchers learn how to scale up experiments and are confident they can get the results they expect, "Then we'll have more credibility when we seek to create a still more powerful machine. I would love to have a demonstration module of Z-Next complete and on the floor by 2022. We would then like to work with NNSA to establish the mission need for a 10-30 MJ facility by 2024." ■

HAVE TRUST

Critical systems should be resilient against attempts to compromise them, cradle to grave

To establish the safety and security of a given technology — as well as its ability to achieve new mission capabilities — the U.S. government calls for repeated demonstration of the technology's effectiveness.

However, increasing dependence on commercial technologies may expose critical government systems to potential malicious alterations during their life cycle. Can these systems be trusted to perform their intended function when called upon?

When the complexities of the development environment elude conventional analysis, a new approach is needed to ensure highly reliable, critical systems.

At the forefront of creating such an approach, Sandia has initiated cross-discipline research and development that addresses the complete spectrum of life cycle threats — including insider and supply chain threats — to the integrity and performance of critical systems.

In this quest, Sandia is partnering with federal agencies, other Department of Energy laboratories and plants, and universities to bring strength and focus to the challenge. Also key is engaging with researchers who reflect the breadth, depth and cross-cutting emphasis of Sandia's many different science and engineering disciplines to advance understanding of, and mitigations for, the risks critical systems might encounter in the development environment. These researchers are exploring a range of questions:

- Designing for trustworthy/self-auditable systems: What technologies in the design can increase the resiliency of critical systems to compromise and also monitor the health of the system throughout its life cycle? Can we design for simplicity to reduce the risk space?

- Threat discovery/analysis technologies: Can we apply what we learn about threats to critical systems to recognize and understand previously unknown threats?

- Managing risk: How can technology help decision makers manage the risks associated with untrustworthy content? Is it possible to quantify trustworthiness?

The Trusted Systems and Communications Research Challenge is using quantifiable engineering-based approaches to evaluate and improve trustworthiness. As part of this project, Sandia is launching two efforts focused on:

- Foundational techniques to support analysis of trustworthiness: Sandia is leveraging existing research in areas such as game theory, supply chain analytics and risk assessment to develop approaches for analyzing trust.

- Use of diversification to improve trust: Sandia is developing verification-based analysis techniques to identify ways to create diversification within systems to increase the difficulty the attacker faces and minimize the impacts of successful attacks.

This research, if successful, will advance the ability to conduct quantitative analysis of trust and lay the groundwork for future development of completely objective techniques for the analysis and synthesis of trust — and also promises to help address challenges in similar problem areas. ■

MEET

Gio
Kao

Education was a big deal around Gio Kao's house. Not just science and math, but art, music and history. "Both my parents are in STEM. Both are math majors," Kao says. "But we took art lessons, Chinese calligraphy, painting, speech and public speaking. My grandfather is a professor of linguistics and archaeology in China and my grandmother has a master's in math and chemistry. It was all about education."

Like his parents who work in the Silicon Valley tech industry, Kao gravitated to computer science — after he gave up on his first goal in life, "to be the first Asian guy in the NBA."

"I played a lot of basketball growing up," he laughs. "But I guess going pro wasn't in the cards."

Kao's family moved from Hong Kong to California when he was 9, and he went to Gunn High School, next to Stanford University in Palo Alto, California, a super-competitive place where he concentrated on technology and was a member of the robotics team. He studied computer science in college, earning a bachelor's degree and doctorate from the University of Illinois at Urbana-Champaign.

A Department of Energy fellowship brought Kao to Sandia in Albuquerque in 2008, funded through a Laboratory Directed Research and Development project. He works in the area of complex systems with a focus on cybersecurity problems. "We develop decision analytics to help analysts make the right choices, from capabilities portfolio management to mitigation deployments," he says. In Sandia's Trusted Systems and Communications Research Challenge, he's helping to develop a risk framework for system risk assessment and management.

Kao recently became manager of the Enterprise Cyber Security team at Sandia's lab in Livermore, California, a move that brought him closer to his family. An avid outdoorsman, he enjoys rock climbing and other sports, and does a mean swing, Lindy hop and salsa.

"I owe so much to my parents for teaching me the importance of hard work and higher education and to my grandfather for being my inspiration and my grandmother for all the life lessons she taught me as a child," Kao says. "I hear their voices always as I move through life."

— Nancy Salem

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LOOKING BACK

Sandia and the science of space-based nuclear detonation detection have been intertwined for more than 50 years, starting with the 1963 launch of the first of 12 U.S. Vela satellites.

Sandia helped develop the Vela satellites to detect gamma rays, neutrons and X-rays that are the signature of nuclear tests. Later satellites included Earth-looking optical sensors to record intense flashes of light from nuclear bursts in the atmosphere. The program presented new technical challenges: how to create a hands-off sensor system for space, shrinking rooms full of equipment to a few hundred pounds and have it all survive harsh environments.

Vela satellites were developed to detect space or atmospheric nuclear testing and verify compliance with the Limited Test Ban Treaty of 1963 and subsequently the Threshold Test Ban Treaty of 1974. They were launched in pairs, marking the start of the U.S. Nuclear Detonation Detection System (USNDS), which supports treaty monitoring.

Sandia worked closely with Los Alamos National Laboratory (LANL) on the Vela program, jointly sponsored by the Atomic Energy Commission and Department of Defense's Advanced Research Projects Agency. Initially, LANL developed Vela sensors and Sandia handled data processing tasks. As the program matured and decisions were made to add to the satellite's capabilities, Sandia took on a larger role in sensor design, particularly the optical sensors.

Vela satellites continued to transmit telemetry data until 1984. Their development led to myriad contributions to subsequent USNDS payloads on Defense Support Program satellites and Global Positioning System (GPS) satellites.

— Sue Major Holmes

During a 1962 visit to Sandia, President John F. Kennedy looks on as Sandia President Siegmund Schwartz, right, explains capabilities of the Vela satellite, designed for detection of nuclear detonations.